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PREFACE.

THE importance of inland water-ways has enormously increased with the growing difficulty of transport, and the whole subject of River and Canal Engineering has become of vital interest. It is a subject which in the past has received scant attention from the practical standpoint; and the author of this present handbook seeks to explain the principles underlying the successful treatment of such work, and then to state concisely and clearly well-ascertained facts free from unnecessary data as to dimensions, costs, etc., which vary greatly in different districts and under different circumstances. The emphasis is therefore laid upon root principles rather than historic and economic details, and the author has drawn upon a wide experience in this country and abroad in dealing with the practical parts of the subject. For theoretical considerations the reader is referred to the classic work of Professor Rankine, "A Manual of Civil Engineering."

The immediate need of attention to this important subject is strongly urged, since our railways are over-congested with goods traffic, our roads are worn with

435195

petrol motors, soon to be further crowded with electric vehicles, whilst commercial aviation has yet to prove its serviceableness. The author hopes this book may prove of use to engineers, municipal authorities, and others.

R. C. ROYAL MINIKIN.

46, Bedford Court Mansions,
London, W.C. 1.

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PRACTICAL RIVER AND CANAL ENGINEERING.

CHAPTER I.

PRELIMINARY.

Of late years the attention of engineers has been called to the permanent improvement of water-courses as an economical medium for the transport of heavy goods between industrial centres.

It has been proved that a river, though presenting serious obstacles to navigation, may, by a judicious system of regulation, be improved so as to permit of an extensive traffic being carried on at a much lower cost than the construction of a canal or railway.

The improvement and maintenance of the transport system of a country or district is always of paramount importance in the economical and commercial development of that country or district, and is a direct gauge of the prosperity of the inhabitants.

To this end one must profit by all the natural features which lend themselves to easy and economical conversion into ways of intercommunication. Railroads must be run through high tablelands or mountainous country and good metalled roads laid over dry hilly stretches.

In very wet lowlands every advantage should be taken of canals—to serve the double purpose of water-ways and a drainage system, and in all countries natural water-courses should be made navigable for the greatest possible length.

River engineers have in late years made great strides in the treatment of the latter, and many hitherto refractory rivers have been made permanently navigable in the greater part of their length. The Elbe, Rhine, Rhone, Niemen and Mississippi carry enormous burdens, throughout the year, since their improvement was undertaken on scientific principles.

River engineering, like all hydraulic work, presents many difficulties, and these can only be overcome by close attention to the local conditions.

The intricate problem of the flow of water, or, rather, of the stream lines, takes a different form in every river, and new factors enter into consideration with the change of the physical and the geological formation of the region through which the river flows. Not only are the stream lines affected by the formation of the river bed, but also by the quantity of water which the river discharges in a given time. A river in flood presents a problem widely different from the same river in the dry season, and a canal does not by any means present the same characteristics as a natural water-course. Until the year 1900 all experimental work on stream lines had been confined to the study of the phenomena observed in canals, and the results obtained had necessarily a very limited application.

It is obvious that the general principles are the same in canals and natural water-courses, but the factors of the latter are so variable that the problem assumes quite another aspect.

The examples given in these pages are from actual surveys and the wide experience of the writer of the extensive natural water-ways of Brazil and Europe, on the one hand untouched by the works of man, and, on the other, old and well-known examples of the engineer's patient training. The subject so treated proves more interesting and certainly more advantageous than theoretical observations of doubtful application, and gives the student some idea of the many material considerations that enter into a due appreciation of the subject.

Water-courses are not only imperfect canals but capricious destroyers of the physical features of their own course, or, in other words, are unstable water-ways.

There is possibly no branch of engineering so intensely interesting as the study of tideless rivers, and to form a decided judgment many difficulties have to be conceived and surmounted. Innumerable factors enter into the subject, and every factor itself being variable, adds to the intricacies of the matter under consideration. Hard and fast rules will not facilitate the problem.

The regime of every river, like the human character, cannot be said to be a duplicate. It may resemble another in ninety-nine points of a hundred, but that one point gives sufficient justification to consider very carefully the differences in the respective works of improvement.

The varying opinions of different well-known engineers upon the same water-way—for example, the Rhone—is sufficient proof of the above remarks.

In the world's history, rivers have played a most important part. Apart from geological considerations, they were the natural means of penetration in new lands, and were the first explored and exploited "vias" of antiquity. On their bosoms colonization and commerce extended in the new world, and in the old the greatest percentage of travelling was effected on their waters. They also formed the natural reservoirs of the drinking water of most peoples, and even at the present day they are widely utilized for this purpose.

The positions of nearly all large congregations of people or towns were practically limited by their access to the sea; and, obviously, before the advent of railways a river was the most natural means of communication. That a river and its tributaries form a most important natural drainage system is undeniable, but like most of Nature's works there are many points capable of improvement, the better to serve the interests of man.

Uncontrolled floods are as prejudicial as a dry watercourse, and the engineer has to undertake to facilitate the free passage of floods, as well as the easy access of navigation.

CHAPTER II.

GENERAL CONSIDERATIONS.

Torrential Phenomena.—Prior to undertaking any work of improvement of water-ways, the natural phenomena of the region necessarily requires to be studied closely.

In all parts of the world the terrestrial history is indelibly stamped on the ground. The great cataclysms of nature, which gave birth to our mountains, have since been modified in their effects by atmospheric agents in the form of snow, rain, etc., which not only eroded the mountain sides, but the debris being carried away by the waters built up the depressions at the lower altitudes.

The continuous action of the torrential phenomena is seen to-day, in the building up of alluvial plains at the outlet of a river into a lake and in the formation of deltas in the estuaries of the larger rivers. Erosion taking place in the higher and more torrential reaches of the river, the material is hurled down to the plains and there deposited.

We may, therefore, express generally the phases of the action as destruction, transport, equilibrium and deposit.

Equilibrium must not be taken to mean that there are parts of the channel unaffected by the current; on the contrary, all parts of the river-bed are subjected to change, and equilibrium as employed denotes that part of the river where erosion is compensated for by deposit.

In the remote geological epochs when the torrents of water had greater force than at the present time they received great quantities of sand and gravel from the hilly regions, and it is through these deposited beds that the rivers wend their ways at the present day. These beds offer little resistance to the action of lateral erosion, and favour the continual changing of the river's course from side to side.

River Bends.—Figs. 1 and 2 are excellent examples of the curious windings of a river's course. The former shows a stretch of the river Yaco, a tributary of the higher Amazon, and the latter a stretch of the river Mersey.

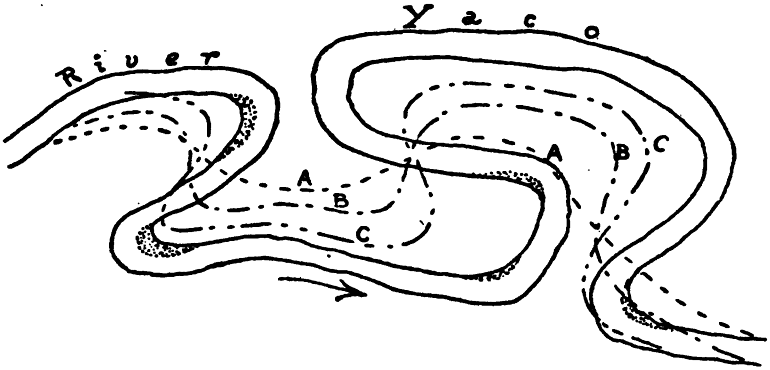

FIG. 1.

In both cases the rivers flow through sedimentary strata, and bend back upon themselves at an angle of curvature of 180°.

The various meanderings of the river Yaco can be closely followed, as the changes are rapid and can be easily traced by the differences in the state of growth of the tropical vegetation, and the material which the river has left abandoned in its old path, such as uprooted trees, etc.

In fig. 1 the original course followed by the river was approximately that as shown by the dotted line AA.

In the course of time the original bends of the river, by reason of the increased local movement of the waters pressing on the concave bank, become more and more sinuous, passing through paths, as shown by dotted lines BB and CC respectively, until the maximum curvature of 180° is attained.

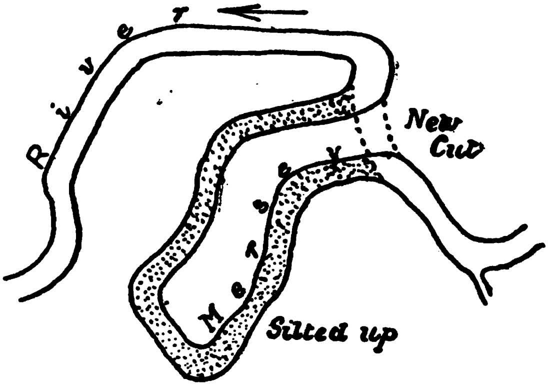

FIG. 2.

The process of carving away the concave bank then goes on at a greater rate, and eventually a rupture occurs in the narrow necks, and the river resumes a more direct course. Fig. 3 shows this very clearly.

The writer had the good fortune of witnessing the rupture of the necks of land shown in this example. After a heavy rain the ground forming the isthmuses, which were only about 15 ft. across at the time, slid into the river-bed, and the increased height of the flood waters attacked the damaged parts vigorously from both sides, and soon forced their way through, reversing the direction of flow in the stretch of connecting channel.

The general progress of these bends is downstream, and in fig. 3 the resulting increased velocity of the waters passing through the shortened channel began to impinge heavily on the lower concave bank, and soon the bends downstream will go through the same change.

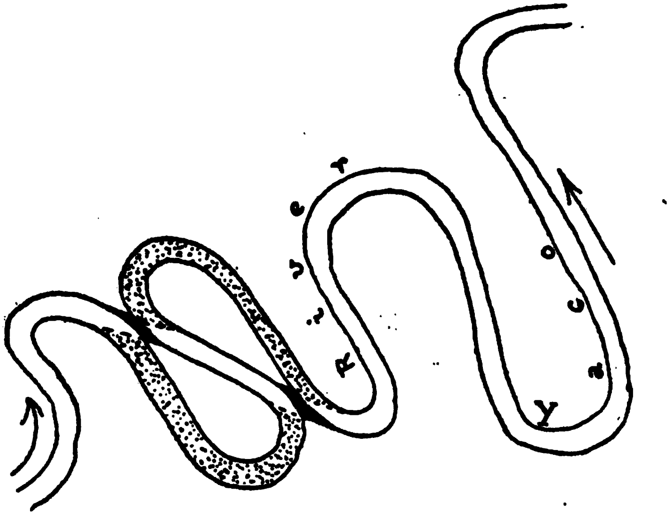

FIG. 3.

Every cubic yard of the banks tumbling into the river gives on the average two-thirds of solid matter, which is transported along the bed and goes to build up a stretch of the river downstream; the other third is carried in suspension by the waters, and is deposited at the river's outlet in the form of mud and silt.

Generally a river widens itself at a slightly greater rate than the rate of deposit, or, in other words, the

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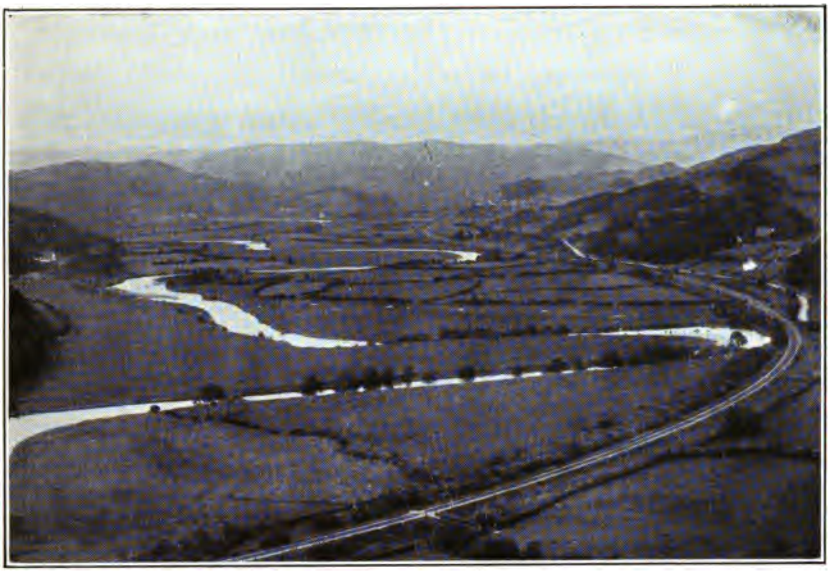
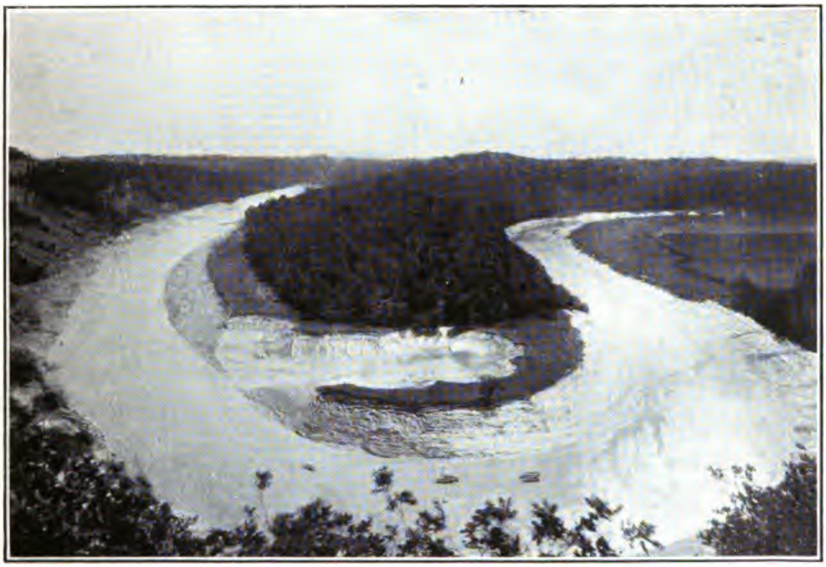
PLATE I.



A.—DOVEY VALLEY, SHOWING THE RIVER MEANDERING FROM SIDE TO SIDE OF A BROAD, FLAT VALLEY.



B.—HORSE-SHOE BEND, SHOWING TREES GROWING CLOSE TO CONCAVE OR ERODED EDGE, AND SEPARATED FROM CONVEX EDGE BY A CONTINUALLY INCREASING STRIP OF LAND.

To face page 8.]

sectional area of the river-bed tends to increase. The action of erosion and deposition in the channel gives to the river-bed a series of oscillations—the destruction of one point being simultaneous with the building up of another downstream. A certain limit is reached after a time, and the waters abandon these two points for others where the same series of changes is repeated.

The solids, gravel, sand, etc., being rolled along the river-bed, eat away the hard surfaces and destroy themselves in the process.

Thus a permanent regime of a river is subject to the condition that the transport of debris is constant throughout the whole length, or, in other words, that no deposit takes place which may not be again transported by the velocity of the current in its locality. Should the flood waters bring down masses of material so large or heavy that the current with the gentler slopes of the lower reaches is incapable of transporting, recourse must be had to dredging.

River Valleys.—Geologists tell us that the earth's crust has been formed very slowly and has suffered tremendous changes of shape during that formation. The arrangement of land and water on the earth's surface has given rise to the theory of the tetrahedral deformation of the earth's crust, where the main mountain chains follow very closely the arrangement as represented by the six edges of the tetrahedron. This theory also points out the fact that all the continents taper to the South Pole, and all the oceans taper to the North Pole.

As all rivers have their source in the high ground, and drain all surplus water off the land to the sea, it becomes obvious that this theory lends interest to the study of the subsequent drainage systems as carved out by the larger and older rivers.

In later centuries this form has not suffered so great alteration from the earth's cataclysms as in the earlier geological eras.

The great influence the terrestrial dislocation has wrought in the subsequent making and unmaking of the river valleys is very important to the river engineer.

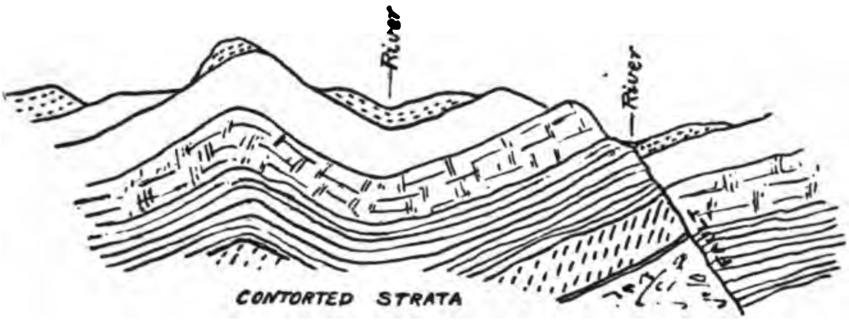


FIG. 4.

There are three types of valleys which directly concern engineers.

1. Rift valleys.
2. Valleys of excavation.
3. Valleys of earth formation.

The former is formed by faulting, and the second is due to denudation, while the third has been formed by the lateral compression of the earth's strata.

Fig. 4 illustrates types 1 and 3.

No better example of the first type can be found than the river Rhine. The land between the Vosges and the Black Forest was, according to the geologists, at one time continuous, sloping away on one side towards Lorraine, and on the other towards Wurtemburg. As a consequence of one of the earth's upheavals, the centre portion slipped down over a great length, and later the Rhine precipitated its waters between the two faults. The second is the more general type, and they are due exclusively to the action of water. They are carved out of sedimentary strata of the lowlands, and follow the natural slope of the ground, twisting about on encountering any obstruction in their paths and becoming wider as they approach the river's mouth.

In these valleys, as indicated in fig. 5, one finds the same geological beds on both sides of the valley, and the various levels at which the river has flowed can be traced by the terraces of deposited material which the river has abandoned at the different stages of its growth on the valley sides.

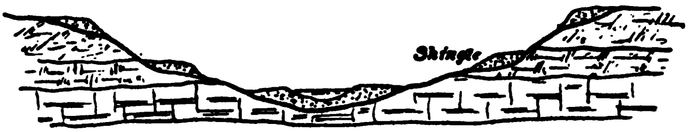


FIG. 5.

It may happen, however, that faults may have occurred subsequent to the deposition of the strata, and a close examination of the valley sides will prove whether or not this is the case. The investigation is not difficult, and well repays the short time spent in its verification. The slope of sides of a valley vary greatly, and depend upon the amount of rainfall and the nature of the strata in the particular zone. Where the rainfall is heavy and the rocks are soft, the valley is generally broad and open, with the sides rising gently from the river bank. When the rocks are hard or the rainfall slight the slope of the sides of the valley become steeper as they recede from the river's edge.

In the case of a river running through strata of very hard rock in a rainless district—as the river Colorado—the classical example—the sides are exceedingly steep and rise shear from the water's edge.

If the strike of the rocks be parallel to the course of the river the slopes of the valley on one side will be greater than that of the other, as the bedding and jointing of the rocks cause the rocks to be more easily disintegrated on the side whose slope is in the same direction as the dip of the strata (plate III.). The river Meuse gives us the third type of valley. The waters of this river find at Charleville a valley already prepared for them, and they take a course through a series of valleys of differing geological decades instead of following the natural slope of the ground, and contributing their waters to the Seine.

Erosion.—Rivers transport and deposit the debris, which results from the destructive action of rain, snow, etc., upon the ground of the watershed. A casual glance at the turbid waters of a river in flood is sufficient to convince one that the waters are transporting more material than that which they erode from the bed. This material has been robbed from the plains by the gullies and streams paying tribute to the larger water-course.

Water is one of Nature's most effective carving tools, and has a chemical as well as a mechanical action—as witness the large limestone caves in the Cheddars as examples of the former, and earth pillars as direct and undisputable action of the latter.

Land forms have been often attributed to earth movement, but after very careful and prolonged investigation it has been recognized that the persistent and powerful processes of denudation have wrought very great changes in the geographical features of a country.

Earth pillars are very common, and are usually to be found in valleys having beds of stiff clay containing fragments of rock, as indicated in fig. 6.

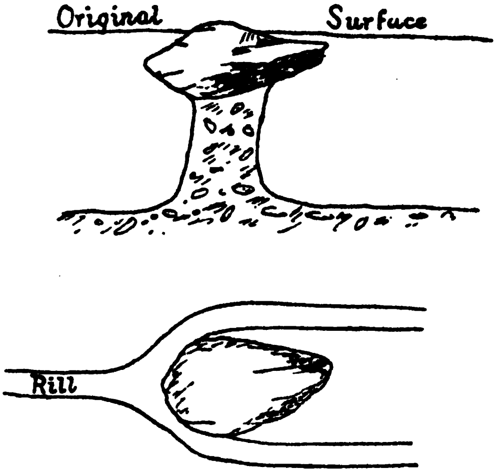


FIG. 6.

After a heavy rain a small stream rushing downhill encounters a large boulder in its path which causes the stream to branch off into two paths, one on each side of the obstruction. These two rills then eat away the clay in their paths downwards and outwards from the boulder, and in time a ridge of clay is formed between the two streams, capped at its upper extremity by the boulder. Subsequently the rain wears away the unprotected portion of the ridge, leaving a pillar of clay with a stone hood in the form of an umbrella or mushroom.

In January, 1910, the author witnessed a wonderful example of the carving power of rain on the prairie lands of the upper Amazon valley. A heavy storm of rain, of two hours' duration, fell on a sandy plain sloping gently towards a depression forming a natural drainage reservoir and communicating to the river Branco by a narrow "igarapè" or ditch. After the cessation of the storm, the plain towards the centre was cut up into an enormous number of rain furrows and ridges diverging from a common centre. Some of the furrows were quite deep—one being no less than 3 ft. deep and 4½ ft. wide and terraced or stepped in miniature after the fashion of the larger valleys.

These examples are common the world over, and give a great insight into the tremendous powers of Nature at work, in the form of rain.

A point worthy of note is that the cross-sections of the smaller furrows were almost rectangular, but that the larger they became the more nearly did they approach that of the letter V. This point has a great bearing upon the principles underlying the flowof water in open channels.

CHAPTER III.

RAINFALL.

RIVERS having their origin in the natural drainage of a watershed generally follow the line of the lowest contour in their passage. The path followed by the river is known as the "line of thalweg," and the district drained of the surplus rain-water is called the "river basin" or "watershed."

We cannot, in the treatment of a river, consider it as an isolated body of water flowing towards the bottom of a valley. It only forms part of a variety of physical conditions incident to the region. The rainfall, the area of the watershed, its geological formation, the physical character of the district, the distribution of vegetation, etc., are all vital points of the regime of a river.

In practice we cannot always take every point into detailed consideration, and this is where the capability of the engineer for analysing justly the various salient conditions proves useful.

The size of a river is proportional to the area of its basin. The following tables give data of a few of the most important rivers of the world:—

River.	Area of basin (in square miles).	Length (in miles).
Amazon	2,250,000	4000
Mississippi . . .	1,250,000	4200
Nile	1,500,000	4000
Yang tse kiang . .	600,000	3000
Danube	310,000	1700
Rhine	75,000	800
Elbe.	55,000	700
Loire	45,000	450
Rhone	38,000	400
Thames	5200	—
Mersey	1700	—

The rainfall in any watershed is dependent upon the climatic and physical conditions, being of greatest intensity in the tropics and diminishing towards the poles. Generally more rain falls in elevated districts than low ones, although there are many exceptions to this rule, depending upon local peculiarities, as for example, the highlands of Peru and Chili, which often escape from the rain-storms, frequent on the lower plains during the rainy season. Rain is also more abundant on the lands of the sea-coast than in the interior. The differences of rainfall are very difficult to explain on account of their erratic nature and occurrence.

The differences of the amount of rainfall or precipitation (including melted snow, hail, etc.) in the same river basin may be considerable. Thus in India the rainfall in the central provinces is but 4 or 5 in., and in the north-eastern provinces the average is no less than 260 in. per annum. Likewise the average annual fall in London is but 24 in., and in the Lake District of Cumberland the average is 180 in., whilst in the immediate neighbourhood of the latter area it reduces itself to 50 in.

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PLATE II.

A.—A RIVER SOURCE.

B.—WATER-WORN CLIFFS—BUTTER TUBS.

To face page 16.]

French engineers have made very careful and elaborate investigations of the differences in the rainfall of the main river areas of the country.

The measurements made in the river Seine basin show that in the neighbourhood of Paris the average annual fall is 24 in., increasing gradually from Paris as the centre, to the coast and the source of the river and its tributaries, to 48 in. This fact is more or less typical of the majority of European rivers.

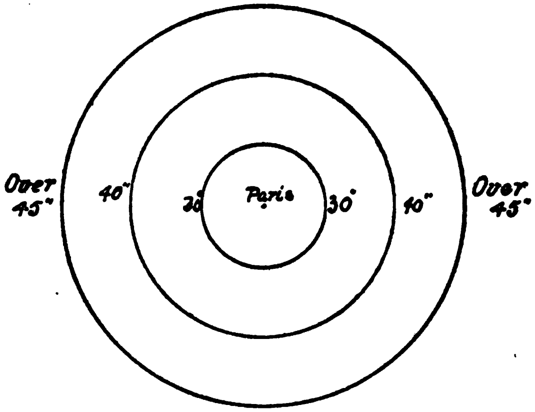

FIG. 7.

The variations in the amount of rainfall in the same district from year to year are sometimes considerable, and the ratio between maximum and minimum may easily be as 3 : 1, but generally it may be taken as 2 : 1.

A moderate steady rainfall for the duration of 24 hours is equivalent to the depth of 1 in. or 65,000 tons of water per square mile, which is equivalent to 2,330,000 cubic ft.

Fluctations in the quantity of water falling in the same locality are much more frequent in warm climates than in the temperate zones.

The rate or intensity of rainfall is of very great importance to the river engineer, and hitherto very little data has been available on the subject. A case in point is that of the Thames valley, where the mean annual fall is 24 in., but on one occasion no less than 5·93 in. were recorded in 90 minutes. That is to say, that the enormous amount of 13,800,000 cubic ft. per square mile had to be accommodated by the drainage system of the locality.

The United States Dept. of Agriculture has prepared tabulated results of various localities, and from which the following table is prepared :—

Locality.	Rate per hour in inches for		
	5 min.	10 min.	60 min.
New Orleans . . .	8·16	4·86	2·18
Milwaukee	7·80	4·20	1·25
New York	7·20	4·92	1·60
Boston	6·72	4·98	1·68
Chicago	6·60	5·92	1·60
Cleveland	5·64	3·66	1·12

An engineer must exercise great care in the collection of the data of maximum and minimum annual rainfall. He should always fight shy of working on an average, and in the case of improvements for flood prevention the maximum known rainfall should be the basis of his calculations, and for water supply the minimum.

The following figures culled from the same source as the above table are interesting, as illustrating the varying character of rainfall throughout the period of 20 years—1871 to 1891 :—

Locality.	Average percentage of days on which rain fell.	Average percentage days with rain.					Heaviest fall in one day.	Maximum No. of consecutive days.	
		Trace to 0·25 ins.	0·26 to 0·50 ins.	0·51 to 1·00 ins.	1·01 to 2·00 ins.	2·01 to 3·00 ins.		Without rain.	With rain.
New Orleans	40·6	24·9	5·0	5·5	3·8	1·0	8·9	28	17
Milwaukee .	44·7	34	5·2	3·9	1·4	0·2	3·7	21	14
New York .	39·6	25·7	6·1	4·8	2·4	0·5	6·2	26	12
Boston .	39·8	25·8	6·1	5·0	2·3	0·5	4·4	25	10
Chicago .	44·0	32·5	5·3	4·2	1·7	0·2	5·6	21	17
Cleveland .	52·2	40·2	6·4	3·9	1·4	0·3	3·6	18	33

In the collection of rainfall statistics deductions should be founded upon records covering periods greater than twenty years if available; any less period may be very misleading.

The use of rain gauges is, therefore, of no use in this respect to the engineer, but as the measurement of rainfall is a direct indication of the amount of water a river will be called upon to carry, gauges enter very largely into the mechanism of flood control. The best type of gauge is that of funnel shape of 8 or 9 in. diameter, and a measuring tube 18 to 20 in. long, as shown in fig. 8.

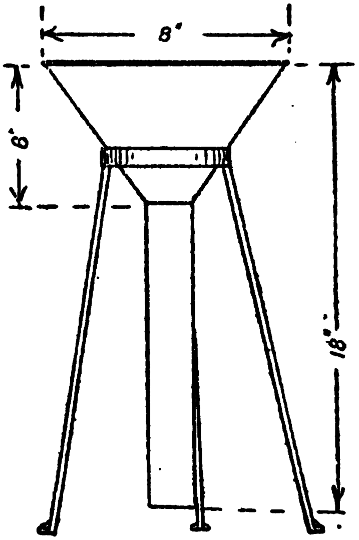

FIG. 8.

The top of the rain gauge should be at least 3 ft. above the ground level to prevent raindrops splashing into it from the ground.

Generally 10 in. of snow is equivalent to 1 in. of rain.

It has been shown by experiment that there is a direct relation between the amount of rainfall, quality of surface strata, and the discharge of a river. The earliest scientific treatment of this subject was undertaken by the French river engineers in 1876, particularly in connection with the Seine valley. They found that the increased discharge of a river, consequent on rainfall, and the time of its appearance at certain points in its course, was subject to the nature and condition of the land upon which the rain fell.

In summer weather a large part of a rainfall is absorbed by the dry earth, while in damp wintry weather a lesser amount is held by it.

Rains are most destructive when falling on frozen or snow-covered ground.

Likewise the air and wind absorb by evaporation an appreciable percentage in the temperate zones, and quite a large amount in the tropics. Hence the amount of water carried off by a river is some fraction of the amount of rainfall, dependent on the climatic and physical conditions of the watershed.

Vegetation.—Vegetation is a most important factor in this connection. Not only does it act as a cooling agent of the air, and thus cause a more abundant supply of rain, but it also absorbs a great deal of moisture and, on the whole, acts beneficially. It regulates the passage of rain waters to the river and reduces evaporation. On flat country it serves as a reservoir of water, equalizes the discharge to the river, and on high ground or mountain slopes impedes the rapid descent of storm waters.

In Brazil, as in many other countries, great loss has been incurred by agriculture through the careless cutting down of trees. Many extensive forests have disappeared within the last 50 years by reason of the foolish custom of burning down a wooded area to form new plantations as soon as the old, for lack of care, became worn out. Not only does the fire destroy the vegetable matter so necessary to cultivation, but in its train grave reversals of the physical characteristics of the neighbourhood have resulted. There is not the slightest doubt, for the proof is as clear as day, that the present lack of rain upon several districts of Brazil is a direct consequence of the criminal devastation of the forests.

The following experience illustrates the seriousness of the question :—

An engineer trekking with a large party and quantities of stores in the southern part of the province of Minas Geraes in Brazil, camped for the night by the side of a stream 30 ft. wide, and the water level 8 ft. below the ground level. All was secured for the night, and the mules hobbled. The weather was fair, and not a sign of rain in the district. About midnight a heavy rumbling noise made itself heard. The engineer rose to the occasion and guessed the cause, but they had only just sufficient time to clear off the mules and the more valuable stores when the flood waters passed at a great velocity some 2 ft. above the old camp level, carrying saddles, etc., to destruction. This happened without it having rained in the vicinity of the camp. It was exclusively a flood due to rain on the stripped summits of the hills a few miles away.

Evaporation.—Evaporation is greater in the summer than in the winter months, and is greater in shallow than in deep water. It is likewise greater from a water surface than from the ground.

In England and France the total annual evaporation from standing water of moderate depth is from 2 to 3 ft., being three times more rapid in the summer than in the winter. In the United States and similar climates the total annual evaporation varies from 30 to 56 in., while in tropical climates exposed to dry winds, as on the north-east coast of Brazil, it may amount to as much as $\frac{3}{8}$ths of an inch per day.

There is less evaporation in cultivated districts than in barren or waste country.

The measurement of evaporation is carried out by means of an open watertight tank 4 to 5 ft. diameter and 30 to 40 in. deep filled with water and placed at ground level. The readings of the variation of depth are taken twice daily, at sunset and sunrise.

In conjunction with the evaporation pan a rain gauge must be used to measure any rainfall that may occur while the observations are proceeding, and due allowance made for the same.

The results as given by these vessels are 30 to 40 per cent. greater than the actual evaporation from a large sheet of water such as a lake or reservoir, hence a good average is to reduce measurements by one-third.

The relative evaporative power of wind is found by experiment to be as follows :—

Wind velocity in miles per hour .	0	10	20	30
Evaporation	1	3·75	5·75	6·25

Harcourt mentions that the evaporation beneath trees is five times less than in the open.

In running water the evaporation is generally greater than in standing water.

An average daily loss for a tropical country like Brazil is 0·2 in., but varies greatly, depending upon whether the position is exposed to the wind or not.

It does sometimes happen that evaporation is greater than rainfall, as, for example, the Caspian Sea area. The sea is gradually lowering its level although fed by several large rivers.

Form of Valleys.—We have already mentioned that the discharge of a river is dependent on the nature of the strata through which it flows. Not only is this the case, but also the shape of the valley and the number and size of its tributaries is more or less determined by this fact.

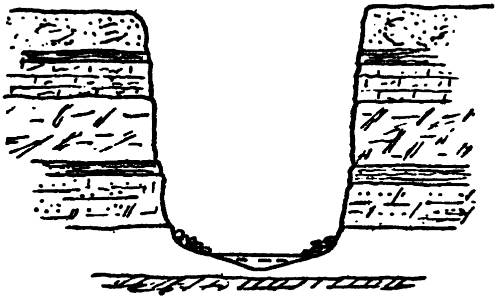

FIG. 9.

The ideal section of a river flowing through a hard strata would be that of fig. 9, as the action of flowing water upon its bed is downwards and backwards, or upstream. So long as there is sufficient fall this wearing away of the river-bed continues, as the example already given of the river Colorado. The most active agent in the destruction of this ideal form of a river valley is that of rain, which, falling upon an impermeable strata, immediately rushes down the line of greatest slope, forming gullies on its way to tributary streams and rivers. The denuding effect is great, and results in the wearing away of the river banks to the form shown by fig. 10.

It is a remarkable fact that a good idea of the nature of the superficial strata of a district can be formed by inspection of the map. Impermeable ground shows a greater number of natural water-courses than permeable beds. In the case of the latter the rain is absorbed into the ground, and finds its way to the draining streams by the slow process of filtration. The denuding effect is not so apparent, and certainly not so great, as in the former case. The general appearance of this type of valley is that of fig. 5.

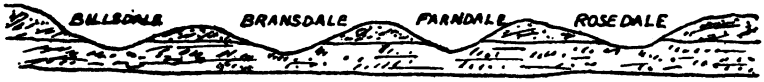

FIG. 10.

The floods on impermeable strata are of larger volume and violence than on permeable strata. Vernon Harcourt expresses the opinion that floods on the former are much more moderate in their consequences than the latter. The experience of the author, however, is exactly the opposite. They are of shorter duration, but by reason of their rapid culmination and the greater velocity they cause much more damage. On the other hand, the floods of the permeable strata are of long duration and lesser volume, and as a consequence more gradual in increase and decrease of water level.

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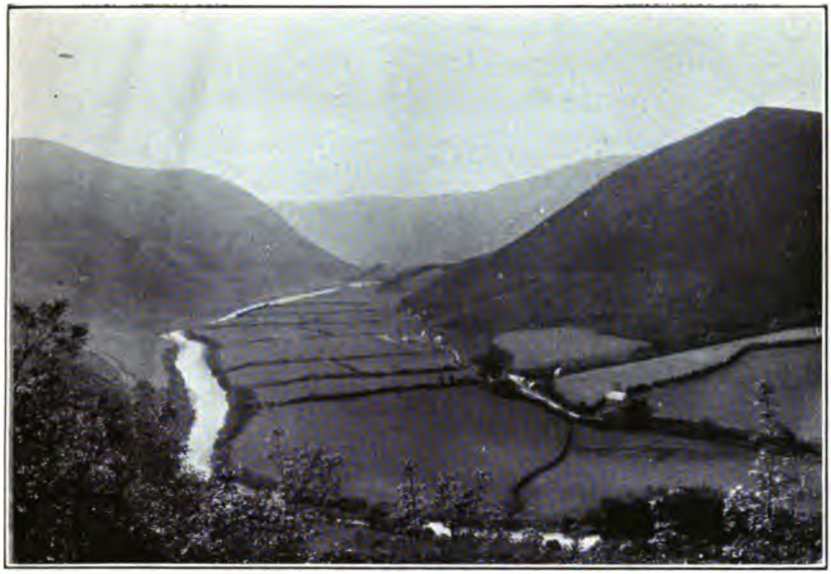
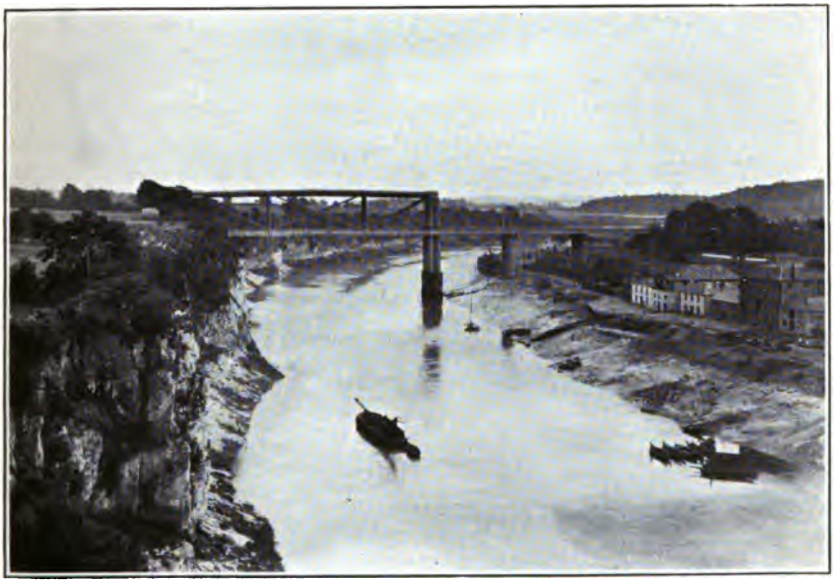
PLATE III.



A.—A COMPREHENSIVE VIEW OF AN IMMEDIATE WATERSHED.



B.—RIVER SEVERN, SHOWING VERTICAL CLIFFS ON CONCAVE BANK.

To face page 24.]

There are few valleys, however, of one nature of strata throughout, and from the source to the outlet the meteorological and geological conditions vary.

Available Rainfall.—The distribution of the rainfall, in conjunction with the nature of the ground, limits the discharge of the river, and it very seldom happens that the rainfall is of the same intensity over the whole of a moderate-sized river basin, nor yet does the same percentage of the rainfall enter the river throughout the various parts of the valley.

We already know that there are many agents absorbing rainfall, and by a judicious system of calculation and statistics we may approximate to the quantity that enters the river in any distribution of rain over the catchment area.

By the comparison of the varying discharges and the volume of rain which has fallen we can compute what is termed the *Available Rainfall.* This quantity varies from 20 per cent. in permeable soils to 75 per cent. in impermeable ground. The general average for large rivers flowing through plains of equal proportions of permeable and impermeable surface is 50 per cent. of the rainfall.

On sloping ground, and on ground in different stages of cultivation these figures vary slightly, but on the whole they serve to guide the engineer in the studying of a new district.

It should be borne in mind that over short periods the available rainfall is a varying quantity. The time of the year, the state of the ground, whether saturated or dry, the intensity of the fall, etc., should all be considered.

In practice it has been found that with the same annual fall the available rainfall throughout the same periods were 85 and 30 per cent. of the total, respectively; and in the same area the available rainfall has dropped down as low as 11 per cent. with a rainfall 9 per cent. greater than in the former cases. These variations were no doubt due to the differences in the times of occurrence of the rain, the heaviest fall in one case being in the spring, and the other in the autumn, when the crops absorbed a large amount of the fall.

The mean annual run off of rivers in temperate climates varies from 1 to 2 cubic ft. per sec. per sq. mile of watershed.

Percolation.—The percolation or filtration of ground in various stages of cultivation can be approximated to from the use of the following table:—

Quality of ground.	Percentage of rainfall.	Quality of ground.	Percentage of rainfall.
Sand . . .	70	Wheat, oats, etc. .	30
Bare ground . .	30	Root crops . .	40
Ploughed ground .	38	Hard wood forest .	45
Grass land, short .	3	Pine wood forest .	85
„ „ long . .	0		

The extensive use of tile drains and open ditches for the drainage of cultivated lands has imposed a greater burden on water-courses, in that it has increased the rate of run off and a speedier collection of percolating waters.

In the Fen district of England provision is made for a drainage of ¼-in. rainfall in 24 hours, and in some cases three times the amount, in spite of the fact that the average annual rainfall does not exceed 30 in.

CHAPTER IV.

RIVER SURVEYS.

RIVER surveys are generally undertaken for one of the following reasons:—

(1) To estimate the volume of discharge at a given time and place, for the purposes of the water supply of a town, or for irrigation.

(2) As a preliminary to the works to be undertaken to facilitate continuous navigation in all seasons of the year.

(3) As a preliminary to works of flood control.

Each of these items requires special study—

(1) Being mostly concerned with the accurate measurements of the cross-sectional area, fluctations of water level at different seasons, and the mean velocity of the water in these sections.

(2) Comprises a detailed study of the shape of the river in plan, section and longitudinal profile, the direction of currents and their intensity, and the average state of the water level, having particular reference to the lowest known level and its duration.

(3) Treats more of the abnormal state of river waters in the period of heavy rains. It requires a general study of the immediate river valley and tributaries, the agricultural, physical, geological and meteorological features

of the country. Careful measurements must be made of the highest known water level, and of the cross-sectional profile of the valley for some distance on both sides of the river.

It is important to remember that in the collecting of information it is advisable to make it as complete as possible, by taking note of any local features, such as positions of isolated houses on river banks, fallen trees, sunken wrecks, boulders, ditches, etc., as they all influence the subsequent plan of the works.

The second item will be considered in more detailed form, since it is more or less representative of the other two, and of much more practical importance to the economic value of a country at the present day.

The first step towards approximating the discharge of a river is the measurement of the cross-section. In the case of large rivers the time spent and the consequent cost is quite considerable.

A wide river with a fairly stiff current proves to be the most difficult; and to illustrate the methods employed we shall take the case of the river Branco, one of the tributaries of the Amazon, of which the author made extensive surveys, etc., in fig. 11. Stations marked 141, 142 to 148, are points at which the theodolite or transit has been set up. This line has been laid out in the usual way, all angular readings being anti-clockwise. Pegs are driven in the ground at these stations and numbered in rotation, offsets to the river bank being taken at each peg, or more often, depending on the accuracy required. From station to station, the average distance was 200 yards.

On the opposite bank at distances varying from 200 to 400 yards, flags of different colours, fixed on long stakes, are fixed to form one corner of the triangulation. So as to avoid confusion in picking up the correct flag station, the best arrangement proved to be the grouping of the flags in two, *e.g.* blue, blue, red, red, yellow, yellow, etc.

Commencing at station 141. Angles ϕ° and α°, between pegs 140 and 142, and peg 140 and y', are measured, as also the distance from 141 to 142.

The instrument is then moved to 142, and the same procedure carried out to measure the angle β° between peg 141 and y', so that a triangle with base 141 to 142 is fixed, and the width of the river can be easily calculated or graphed, the latter being the more usual. The whole of the survey, with the exception of the cross-section profile, is carried out in this manner. It is very speedy, and with a tacheometer, even in the densest forest growing to the water's edge, 2000 yards can be done in one day by a skilled observer. In a run of 450 kilometres the author averaged 4000 yards per day, having no other assistants than South American Indians who spoke no language but their own.

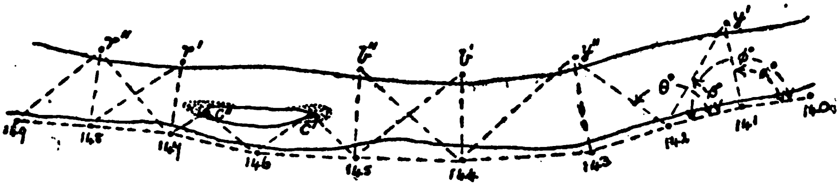


FIG. 11.

To measure the cross-section a canoe with two paddlers, one soundsman, and one recorder was used. The soundsman was placed in the bows and was supplied with leads and painted graduated staffs to measure the depths. An assistant supplied with a signalling flag, was stationed immediately behind peg *b″*, and by pointing the flag right or left showed the canoe which way to move to get on to line *b′*–144.

When the centre of the canoe was on this line the assistant would hold the flag vertically above his head, and the soundsman would then take the reading on his sounding rod, calling it out for the recorder to enter it in his book. At peg 145, an observer keeps a transit trained on the soundsman, and as soon as he notices the rod plunged into the river he takes the angular measurement from 144 to the boat. The soundsman has instructions to measure the depth every 20 yards, as near as he can guess, and the rough approximation which results very seldom exceeds 30 yards, and is generally less than 20 yards.

The readings of the angles at the instrument when plotted cut the line *b′*–144 at the positions of the respective soundings.

This method is suitable for large open rivers, and has proved very satisfactory even in a strong current.

Where more accuracy is required, in smaller channels, a rope or wire can be run across from bank to bank, doing away with the assistant, and if bits of cloth are tied upon the wire at the required interval only the boat party will be necessary.

The section of the river at peg 144 is shown in fig 12. At all points where a cross-section profile is measured it is advisable to take levels 200 yards in from the river bank. This can be done very quickly with a tacheometer.

It is very important that changes of water level be recorded at frequent intervals throughout the survey. The most practical means of doing this is to plant graduated pickets at intervals of 4000 yards in some sheltered reach of the river, and standard pickets to which all the others are referred every 10,000 or 12,000 yards.

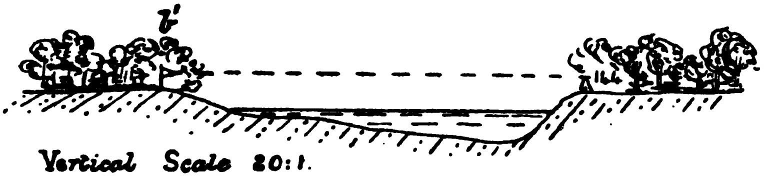


FIG. 12.

In fig. 13 S is the standard picket, and U and D are the upstream and downstream pickets respectively. S is generally placed near the camp to facilitate inspection at frequent intervals, whereas the readings of pickets U and D are only taken in the morning and evening, at more or less the same time, and

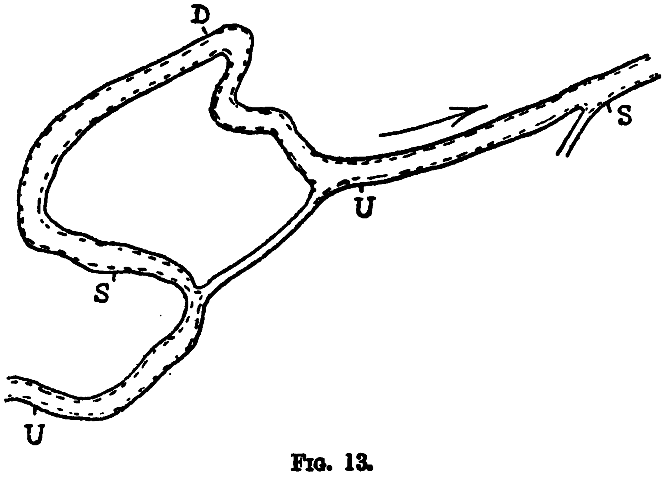


FIG. 13.

the readings of all pickets are compared. In recommencing work after a break overnight, one must note the level of water at the peg station where the last alignment was finished, so that any difference may be corrected. It is not necessary to keep more than three standard stations going on an ordinary river survey, excepting in the case of preliminaries to works of flood control, when the time of arrival of a flood wave at the various points is required.

It is also advisable to put a standard picket just below the confluence of a tributary, so that the effect of the latter upon the main river is noted. It is not unusual to have a difference of water level of one foot in the same place, between morning and evening, while carrying out the alignment. Were this not noted a very awkward and misleading longitudinal profile would result, expecially in the case of a smooth flowing river of slight fall.

Discharge.—When it is necessary to determine the cross-sectional area for the purposes of calculating the discharge, three river-bed profiles are measured at intervals of 50 yards, and the mean area of the three is then taken for the purposes of the calculation.

Thus $$D=AV$$

where $D=$ discharge in cubic feet of the water passing through the measured section per second, $A=$ mean area of cross-section, obtained as above, in square feet, and $V=$ the mean velocity of all the filaments of water flowing through the section per second.

Thus, if we could arrange some manner of observing the several velocities of the filaments the mean of the

PLATE IV.

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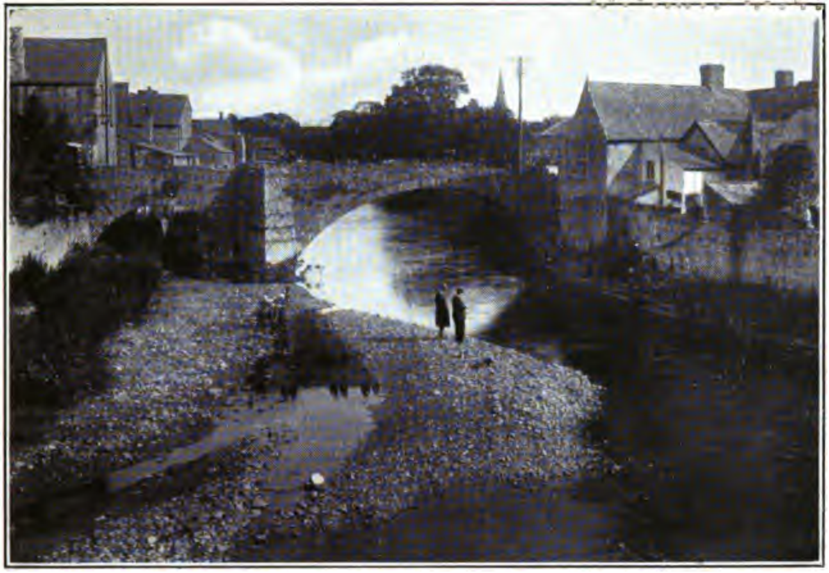
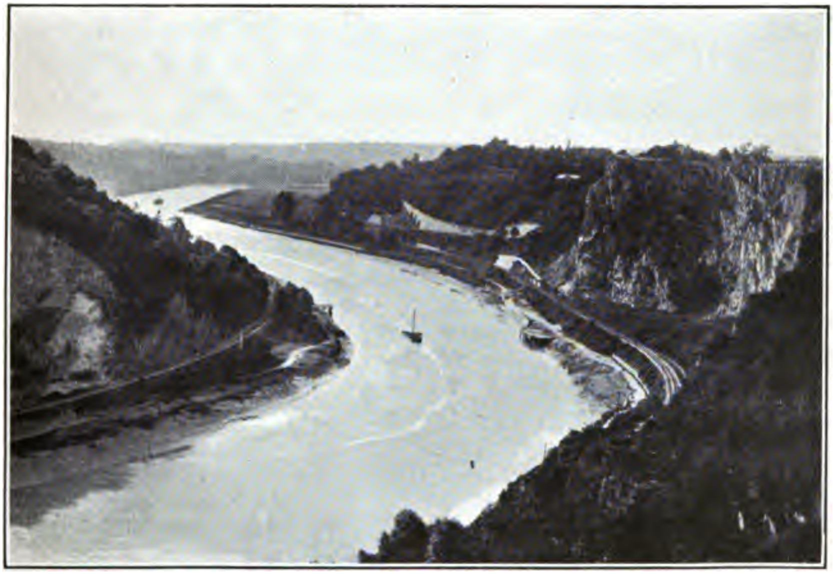


A.—A PHOTOGRAPH OF A SMALL RIVER WHICH FORCIBLY ILLUSTRATES THE MODUS OPERANDI OF THE LARGER RIVERS.



B.—RIVER SEVERN, SHOWING PRECIPITOUS CLIFFS ON CONCAVE AND GRADUALLY SLOPING CLIFFS ON CONVEX BANK.

results would be the mean velocity. This is not possible; we therefore approximate to the true mean by taking as many observations as possible.

Observation for velocity of current may be divided into two classes—

(1) That in which the end aimed at is to estimate exactly the amount of water crossing a given section, perpendicularly to the course, and

(2) That which treats of the immediate direction of the current.

The first is carried out by means of current-meters and gauge-tubes, while the second is more general, and is done by means of floats.

The principle of the current-meter is that of a reversed propeller or turbine which, being attached to a horizontal shaft, causes it to revolve. The number of revolutions recorded gives the necessary data from which to estimate the velocity at that particular point.

The currents of a water-course, however, are not all in the same direction. There are currents crossing the channel diagonally, and others flowing in a spiral manner in the general direction of the stream. For this reason weighted rod floats with a length slightly less than that of the depth of section are preferable.

Experiments carried out by Major Cunningham show that the velocity of a rod float is very nearly equal to the mean velocity of the vertical plane in which it moves, and Mr. James B. Francis, as a result of his exhaustive hydraulic experiments, confirmed the fact that tube or rod floats were the most reliable form of float for the direct measurement of the mean velocity.

In the comparison of the calculated discharges of the canal at Lowell, U.S.A., from the mean velocity, as measured by tube floats, with the measured discharge over the weir, he found that the former gave rather high results.

This was due to the fact that the rod not entering into the layers of low velocity on the canal bed was not affected by them, and therefore registered too high. The correction suggested by him is as follows:—

$$Q = cq$$

where Q = actual discharge

q = discharge as determined by tube floats

c = co-efficient $= 1 - 0{\cdot}116(\sqrt{D} - 0{\cdot}1)$

$$D = \frac{\text{distance of bottom of float from canal bed}}{\text{depth of stream}}$$

Submerged floats vary greatly in construction, for every engineer has his own ideas as to which is most suitable. They are all alike in one particular, in that they all have a large submerged portion connected by a silken cord or wire to a small surface float. The immersed portion is just sufficiently weighted to keep the connecting cord stretched.

A few of the various types are as follows: Small wooden kegs 8 in. diameter, weighted with lead; wooden cylinders 6 in. diameter, 12 in. long, weighted with lead; wooden spheres 8 in. diameter; small copper spheres 5 in. diameter; thin galvanized iron plates crossed in the centre at right angles; open thin copper cylinder with air space at the upper end.

The surface floats in connection with these are practically similar, being small wooden discs from 3 in. to 6 in. diameter and ¼ in. to 1 in. thick.

The two latter types are perhaps the most suitable forms of the submerged float for obtaining an accurate value of the velocity. They present a relatively large intercepting area to the current, and are thus carried along with it, and are not so much affected by secondary currents as the closed cylindrical and spherical type.

Fig. 14 illustrates the open type of float, the circular wires merely serving as stays. The plates are usually 12 in. by 9 in., and the floating disc 8 in. diameter.

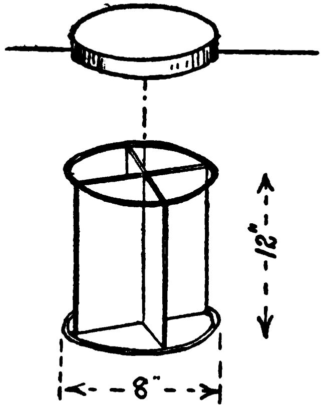


FIG. 14.

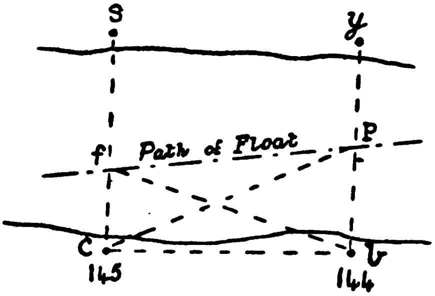


FIG. 15.

The use of double floats has been very popular in India, and good results have been obtained.

Mean Velocity.—In fig. 15 the two river sections 144 *y* and 145 *s* have been measured, and we now proceed to measure the velocity of the water filaments. At *s* and *y* a flag is posted, and at the stations 144 and 145 an instrument is placed. These two stations (say, *b* and *c*) must be in view of each other, and the distance apart accurately measured, likewise the distance *sy* must be equal to *bc* and parallel to it. The angles *scb* and *ybc* should be as nearly as possible 90°, and the sections perpendicular to the current.

The float is dropped in the water upstream of the line *yb*, and both observers train their instruments on the float, open sights being used. As soon as float reaches line *yb*, observer *b* signals to observer *c*, and at the same time the recorder or assistant opens his stopwatch. The reading of the instrument of the angle *scp* is noted and the instrument then swung round to *s*.

Meanwhile, the observer at *b* follows the float until the observer downstream signals that it has reached the line *cs*, whereupon he notes the angle *ybf*, and the recorder closes the stopwatch and notes the time of passage. This process is repeated over a number of longitudinal sections to arrive at the mean.

The path followed by float is given by this method, and the information gathered on the direction of currents is worth the use of the two instruments.

In the case of a narrow river cords or wires can be stretched across the channel.

The velocity of the water in an open channel varies in the horizontal as well as in the vertical plane.

In fig. 16 *a* are shown curves of equal velocity for a section of a river, and at *b* a curve of the surface velocities at the same section. At *c* are shown curves of the velocities in the vertical plane at *xy* and *rs*.

Considering the sections *a* and *c* we notice that the maximum velocity is attained by the filaments at the centre of the closed curves, and that it is nearer to the surface than to the bed.

The average depth below water level of the maximum velocity is, under general conditions, 0·25 of the depth of the section. The roughness of the bed affects this, and in canals and very smooth flowing rivers it is about 0·20 of the depth. The smoother the bed the flatter the curve *c* becomes, or the differences of velocities become less.

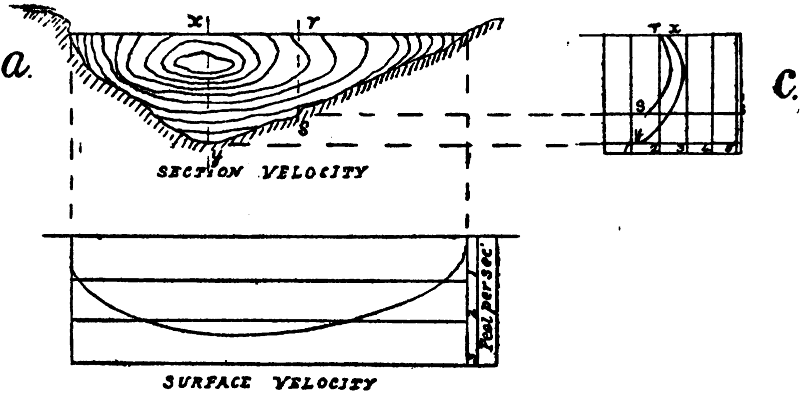


FIG. 16.

The wind plays an important part in the distribution of velocities. When the wind is with the current the surface velocity is increased, and the curve is straightened, as indicated in fig. 17, at the upper end, and when against the direction of flow the surface velocity is decreased, increasing the curvature as shown.

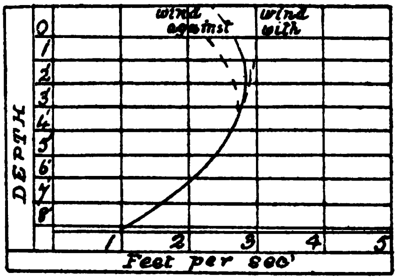


FIG. 17.

Generally the mean velocity is equal to that at about six-tenths of the depth below the surface, and in a hurried survey a float sunk to this depth in mid-channel will give satisfactory results. When more time can be spent on measurements the mean surface velocity can be found, and the result multiplied by 0·75 will give the approximate mean velocity of river.

The author often had occasion to use oranges as surface floats, for the purpose of determining this velocity, with great success.

The curve of surface velocities, fig. 16, shows that the velocity decreases slowly from a maximum in mid-stream towards the bank, and when quite close to the edge drops abruptly to a minimum with deep banks, and zero when shallow.

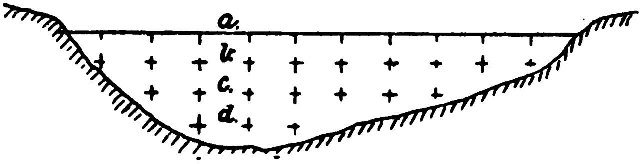


FIG. 18.

To produce a complete set of curves at one section of a river survey is a distinct advantage, specially if the section profile of the river-bed is similar over a large distance. The expense incurred at the one point is regained later, by a speedy treatment of the other similar reaches.

Considering fig. 18, let *abc* represent the planes, and the crosses the points at which the velocities have been measured.

The mean velocities on the planes *abc* are then calculated, and the mean of the three will then give the mean velocity of the stream.

Then $$V = C\sqrt{RS}$$

where V = mean velocity in feet per second

R = the hydraulic mean depth in feet

$$= \frac{\text{area of section}}{\text{wetted perimeter}}$$

$$S = \text{slope of bed} = \frac{\text{friction head}}{\text{length}}$$

C = co-efficient varying with the nature of bed.

We can introduce the value of V as found by experiment above, and deduce the value of C, which can be applied to the remaining river sections.

Thus $$C = \frac{V}{\sqrt{RS}}$$

The value of C as found by the author on the shallow Amazon tributaries was generally 70, and where the maximum depth did not exceed 6 ft. the following thumb rule proved useful:—

$$V = (40 + 10R)\sqrt{RS}$$

Since Chezy introduced the formula $V = C\sqrt{RS}$ little change has been made in its general form with the exception of the co-efficient C.

From the experiments conducted on the Seine M. H. Bazin has introduced the following value for

$$C = \left\{\frac{1}{0{\cdot}00008534\left(1 + \frac{4{\cdot}1}{R}\right)}\right\}^{\frac{1}{2}}$$

Many other experimenters have also succeeded in producing most complicated sets of figures which are more suitable for professors than engineers, for it is nigh impossible to commit them to memory.

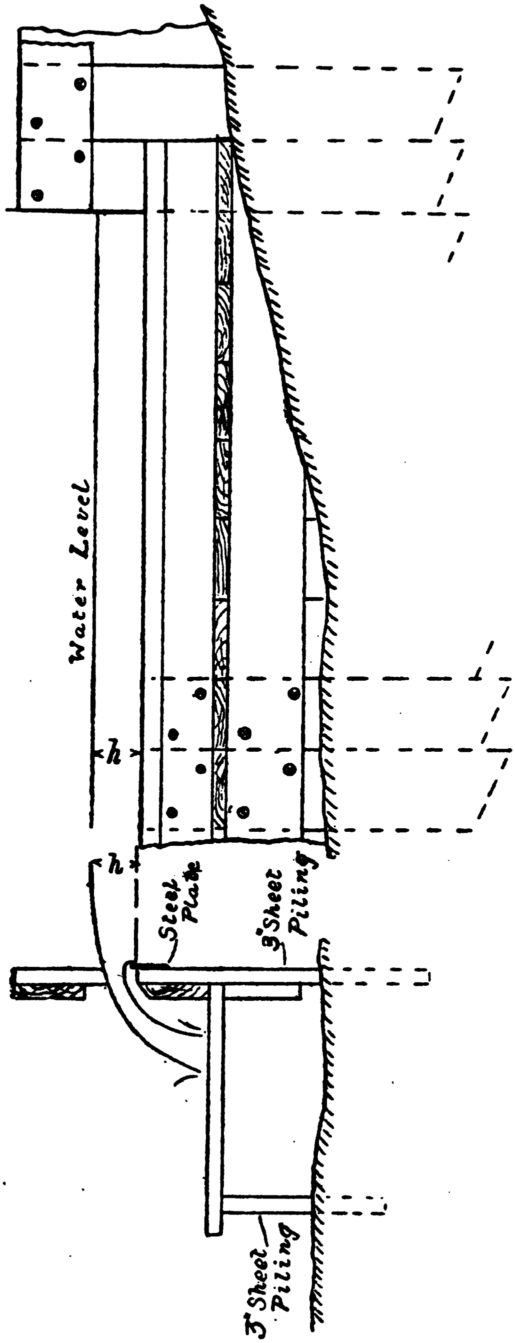


FIG. 18A.—MEASURING WEIR.

The co-efficient C, as found by Bazin's rule, is little less than the co-efficient given in the thumb rule.

Measuring Weir.—To determine the discharge of small streams it is preferable to build measuring weirs across the channel. The usual pattern is a vertical wall of tongued and grooved 3-in. planks with a horizontal crest edged with sheet iron (see fig. 18A). The edge of the upper plank must be chamfered so as not to interfere with the free fall of the water.

If Q = theoretical discharge, cubic ft. per sec.

PLATE V.

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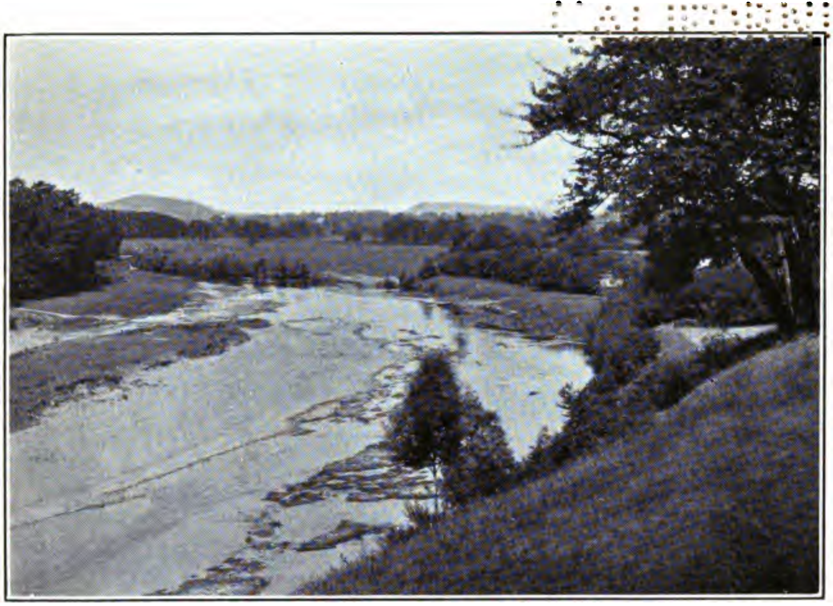
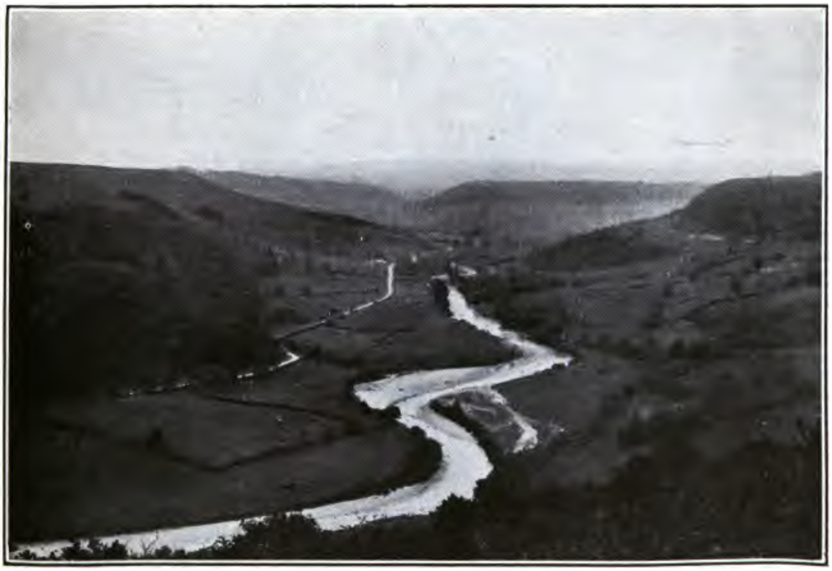


A.—RIVER WYE, SHOWING DEFINITE ACCUMULATION ON INNER BANK AND RIPPLES ON WATER CAUSED BY SAND WAVES.



B.—SWALEDALE, A GENTLY SLOPING VALLEY.
Note the break through by floods on the near bend.

To face page 40.]

If q = actual discharge, cubic ft. per sec.
h = head of water above crest of weir, ft.
l = length of weir crest in ft.
Then the theoretical discharge is

$$Q=\tfrac{2}{3}lh\sqrt{2gh} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now the actual discharge must be some fraction of the theoretical discharge,

therefore, let $c=\frac{q}{Q}$, and we get

$$q=\tfrac{2}{3}clh\sqrt{2gh} \quad . \quad . \quad . \quad (2)$$

The value of c as determined by a large number of experiments by Mr. Francis and others averaged 0·62. Inserting this value for c in equation (2), where C is a constant,

$$\begin{aligned} C&=\tfrac{2}{3}\times 0{\cdot}62\sqrt{2g} \\ &=3{\cdot}33 \end{aligned}$$

which is the constant of the Francis formula and gives the following simple equation, which is reliable for all heads of water between 6 and 24 in.

$$q=3{\cdot}33l\sqrt{h^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When the length of the crest is less than the width of channel and less than 10 times the head of water a correction for end contraction must be applied. The formula (3), with two end contractions then becomes

$$q=3{\cdot}33\left(l-\frac{h}{5}\right)\sqrt{h^3} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

CHAPTER V.

WATER-WAYS.

THERE are four important classes of natural waterways—

Torrents.
Torrential rivers.
Semi-torrential rivers.
Smooth flowing rivers.

Torrents.—A mountain torrent has its source in a large reception basin or bowl-shaped collecting cavity called a "cirque" or "corrie," from whence it empties itself through a gorge or channel between the mountains. In the passage of the rushing waters from the cirque a great amount of debris is carried along from the enclosing channel and deposited on the adjoining lowlands in the form of an alluvial fan or "cone of deposition."

A very interesting and instructive report of the tremendous power of a torrent was made by M. Schlumberger in August, 1876. It is as follows:—

"I had just left Barcelonette at half-past two, at the moment of the arrival of the storm over the reception basin of the Torrent of Faucou. Very little rain had fallen in the valley, but a great deal appeared to have fallen on the hills. Arriving at Faucon I waited by the apex of the cone of deposition and in the throat of the channel I saw a formidable mass of mud majestically descending towards me.

"Where I was standing the torrent bed was about 80 ft. wide and 20 ft. deep, and was almost dry, in spite of the rain which had fallen in this neighbourhood. . . . The black mass advanced without noise, and was soon passing by me at a velocity of about 5 ft. per second over the bed which had a slope of 1 in 10 (see fig. 19).

"It was veritably an amalgam of earth and of blocks of stone of all sizes, having the fluidity of mixed cement. In front, partially buried by the thick mud, a vanguard of large blocks of 5 or 6 cubic yards was being pushed downstream, and on encountering any obstacle in their path, were momentarily stopped and swallowed in the oncoming mass. The velocity was very erratic, sometimes it moved fast and then so slow that it appeared inert. At the slightest obstacle, the blocks were held up in their passage and a jamb occurring, the vanguard of blocks held up the whole of the mass from bank to bank forming a temporary barrage (see fig. 20).

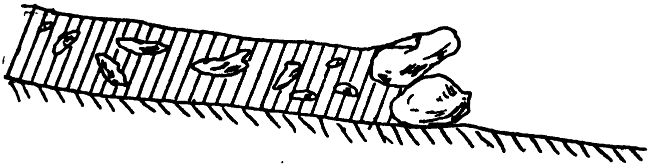


FIG. 19.

"However, the pressure of the flowing mass soon raised the level of the mud stream to 15 ft. and a sudden break occurring in the dam the whole was accelerated downhill in a veritable confusion of stones and mud. The larger blocks became enveloped, and the velocity became more uniform. Now and again the large blocks would be lifted above the stream level on encountering some obstacle, and then as suddenly swallowed up again on overcoming it (see fig. 21). The depth of mud now on the river-bed was more uniform, being about 12 ft., and the surface in section profile being convex to the sky when rising, and slightly concave when descending (see fig. 22, *a* and *b*).

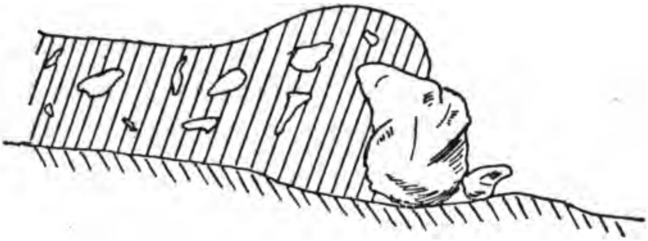


FIG. 20.

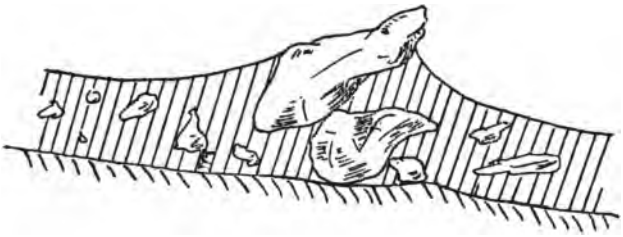


FIG. 21.

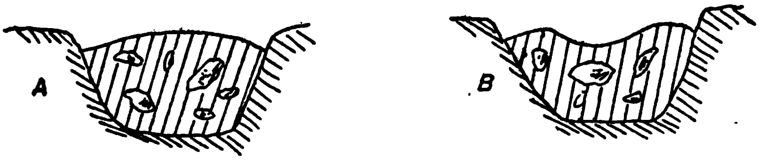


FIG. 22.

“ As the stream passed on the succeeding mass became more and more fluid and the velocity higher.

"Suddenly the waters arrived with a noise and rush, flowing furiously down the centre of the mud, which still moved slowly downhill, as in fig. 23.

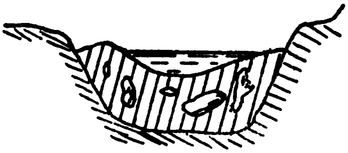


FIG. 23.

"A tremendous fracas ensued, the waters rushing along with great force formed waves about 6 ft. high and pushed along in their front the large blocks left by the mud. The noise of the waters and the stones beating against each other was terrific.

"The water soon overtook the vanguard, and gave the whole mass a further impetus on its way.

"Soon the water had carved out a channel for itself through the mud, robbed the latter of its passenger blocks, and gave them an express passage to the plains (see fig. 24).

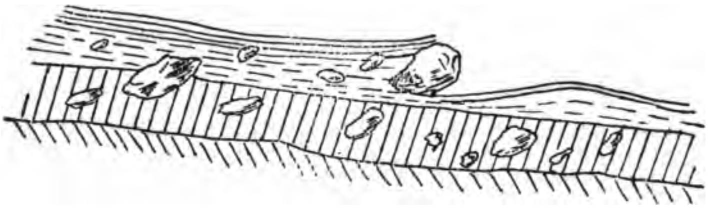


FIG. 24.

"On the cone of deposition the velocity of the mud became very feeble, and the water passed over it with a velocity of 9 to 12 ft. per second, still pushing the blocks along in a straight line from the throat of the apex.

"As the waters progressed they became less violent, and eventually arrived in the main stream merely laden with mud and pebbles, having deposited the large blocks in the alluvial fan."

When the velocity is checked in the lower valley the waters are forced to deposit their burden of heavy stones, and these are deposited in the form of a cone, over which the water rushes.

This report gives a very succinct idea of what occurs in the higher ground of a watershed, and demonstrates the tremendous power that a relatively small amount of water can exert.

The coarse gravel beds found in the valleys of the Rhine, the Rhone and the Po, are examples of the old cones of deposition of the large torrents which have flowed in these valleys.

A considerable amount of mischief is often caused by these mountain torrents, and the French government have caused many experiments to be carried out to alleviate the damage done to cultivated ground in their vicinity. The building of dams across the upper parts of the channel and at the outlet of the cirque does not suffice to reduce the destructive effect of the current. It is necessary to carry out a systematic training of the channel throughout its length. As the majority of the debris carried along the torrent bed is carved out of the channel or walls of the gorge, some method of protection is necessary.

In Switzerland the large blocks which strew the torrent bed are utilized to build up the sides of the channel, thus limiting and directing the current in a regular course, at the same time leaving a clear bed for the free passage of the waters. Naturally this tends to increase the velocity and erode the bed, and therefore small cross dams are built across the bed at the lower end of the wider parts of the channel.

The same training must be carried out in the cone of deposition; and the waters must be enclosed between two firm banks, until its velocity is sufficiently lessened to allow it to continue on its way, powerless to do damage.

The sum total of the effect of the works is to reduce the enormous amount of detritus, and to break up the velocity of the waters on reaching the plain.

Torrential Rivers.—Torrential rivers are those of very variable discharge, and are subject to sudden and tremendous floods. They generally have their source in high impermeable ground, and commence their course as a torrent. Almost without exception a diagram of the slope takes the shape of a curve concave to the sky, that is, with a diminishing fall from the source to the outlet.

The river Rhine between Lake Constance and Mannheim, where it passes over a high tableland, is one of the few exceptions. The fall from Basle to Mannheim being more pronounced than in the stretch immediately above it, the curve of fall is convex to the sky for this short distance.

Variations of the discharge, and consequently of the depth of water hinder navigation, and for that reason such rivers are the most difficult and expensive to regulate. The ratio between the minimum and maximum discharge may vary from 1 to 300 to 1 to 40. The best-known rivers of this class are the Rhone, the Marne, and the Durance.

The great balancing effect of a lake in the course of a torrential river is shown in the case of the river Rhone. The fall from its source to the lake of Geneva is very steep, and the velocity of the waters very high. From the outlet of the lake to Lyons the fall is still considerable, being 7 ft. per mile for the first half, falling to 5 ft. per mile in the sector above Lyons.

During the dry season the average discharge at Lyons is 200 cubic metres per second, and just below the confluence of the Rhone and the Durance 400 cubic metres per second. At the same places, during the time of flood, 7000 cubic metres and 14,000 cubic metres have been measured, respectively; or in the ratio of 1 to 35. This considerable and sudden variation is productive of disastrous results. In general, with a semi-torrential river, there is some point in its course at which the effect of a flood diminishes, but in the case of a torrential river the effect is only one of time. The flood travels as a wave, making itself felt progressively throughout the length of the river.

The attached table of discharges of the Rhone show this steady increase as the wave proceeds downstream.

At Lyons—above the confluence of the Saone	6500	cubic yards.
„ below „ „ „	8800	„
Tournon	9200	„
Above the confluence of the Tsère	9200	„
Below „ „ „	12,000	„
Valence	12,000	„
Confluence of the Drôme (below)	13,000	„
Above the confluence of the Ardiche	14,000	„
Below „ „ „	15,000	„
Avignon	14,000	„
Confluence of the Durance (below)	17,500	„
Beaucaire	17,500	„

It will be noticed from these figures that, between Tournon and the confluence of the Tsère and below the confluence of the Tsère to Valence, there is no change in the maximum discharge, excepting that due to the tributary Tsère, whereas between the confluence of the

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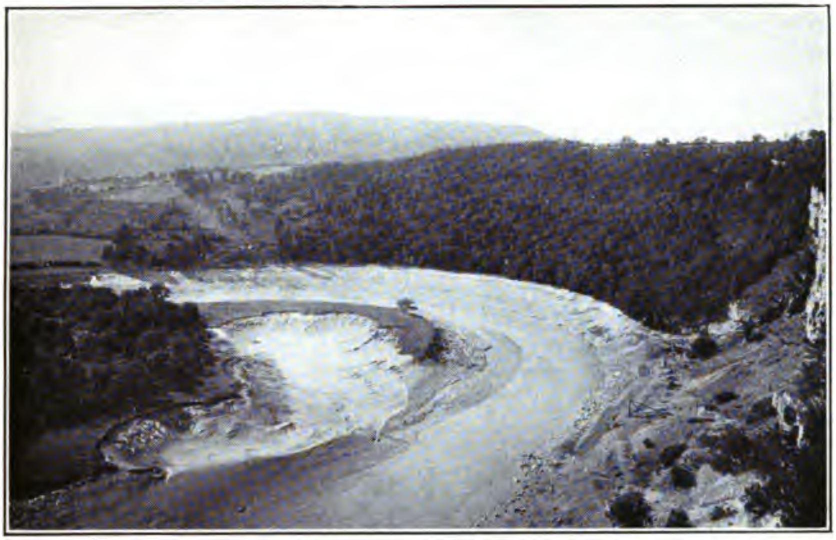
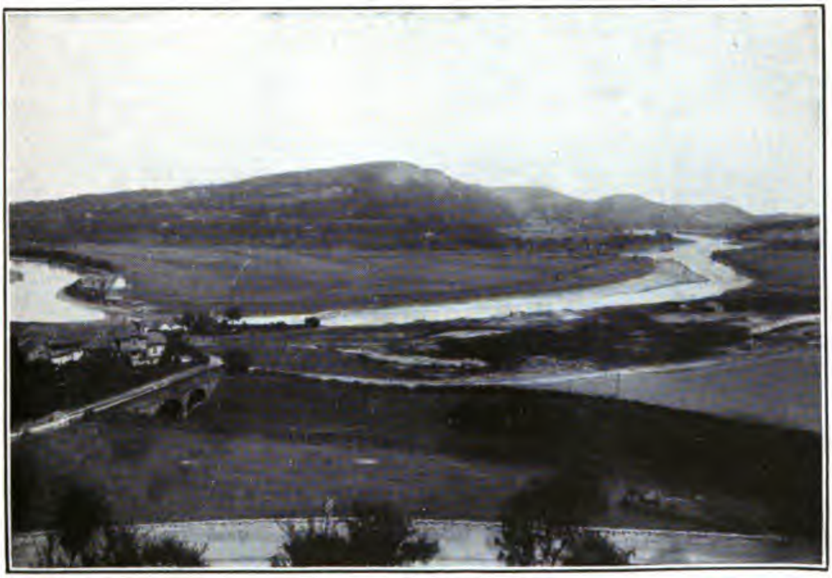
PLATE VI.



A.—HORSE-SHOE BEND, SHOWING EROSION OF UNSTABLE TONGUE BY WEATHER AND FLOODS.
Note protecting lip on upstream side.



B.—AN ALLUVIAL VALLEY—RIVER TAY.

To face page 48.]

Drôme and above the confluence of the Ardiche there is an increase of 1000 cubic yards.

From the Ardiche to Avignon we have an example of what occurs on a semi-torrential river, a reduction in the discharge as the water progresses.

On reaching the very torrential Durance, the main stream is swollen by 3500 cubic yards per second. The figures are typical of all torrential rivers. The variations of the discharge are sudden, and of great rise and fall (fig. 25).

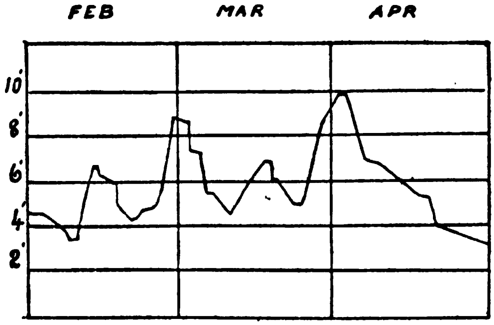


FIG. 25.

The largest tributaries of the Rhone are the Saone and the Durance. The latter is specially important, as it has been prolific of a good deal of difficulty from an engineering and economic point of view.

For the first 100 miles its course runs through a very narrow valley, and in places precipitous cliffs with a fall varying from 45 ft. to 15 ft. per mile.

The remainder of its course, to its confluence with the Rhone, a distance of 80 miles, the valley becomes flat and the river-bed varies from 1000 to 1800 yards wide with an average fall of 10 ft. per mile. The soil of the lower valley is distinctly unstable, and the river in the dry season wanders about this wide bed, zigzagging in a narrow channel from bank to bank. The high velocity of the waters in the time of flood erode the banks at an excessive rate, tending to turn the alluvial plain into one vast gravel dump. To counteract the divagations of the river and to reclaim the agricultural land that the successive floods had robbed of their sub-soil, a system of transverse levies in the form of T's were constructed in pairs, on opposite banks at 800 to 1500 yards stretches between each pair according to the slope of river-bed.

The high velocity of the current and the excessive fluctations of the discharge make these rivers unsuitable for navigation.

The chief necessity is the application of the art of the engineer to give a free passage to the floods and yet to break the velocity of the current, and so to control the wanderings of the river channel that the summer water level may be sufficient to allow of navigation.

As these rivers have large slopes, the solution of the problem lies in the modification of the longitudinal profile. The waters have to be so trained that they tend to reduce the fall, the endeavour being to lower the higher levels rather than build up the lower.

In the higher reaches the problem becomes one almost entirely of flood control, and to that end afforestation becomes specially important to reduce the rate of collection of waters in the reception basins. The velocity of the waters in the channel itself being reduced by weirs and cross-dams, which also serve the double purpose of collecting the debris in transport, on their upstream faces.

Semi-Torrential Rivers.—Rivers which are torrential in their upper reaches, and which become less violent as they approach their outlets, are classed as semi-torrential rivers.

As examples of this class the Loire and the Garonne are the best known, but the Rio Branco, a secondary tributary of the Amazon, is typical, and is the river on which the author spent 12 months' incessant study, commissioned by the Brazilian government to make a report thereon.

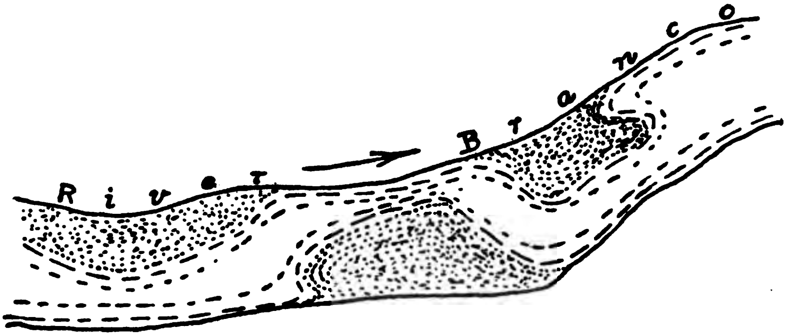


FIG. 26.

The conditions of this class of river are identical, no matter in which continent they are found. They are liable to sudden floods, which last longer than those of torrential rivers, but similar to the latter in the fact that in the dry season they have a major and a minor bed, or the river channel wanders about in the larger bed making navigation difficult or impossible (see fig. 26).

The Rio Branco has its source in the highlands of the frontiers of Venezuela and Brazil. Its fall in the higher reaches being 5 ft. per mile with consequently a high current and a straight course. Below the confluence of the torrential tributary Tacutu, which brings the drainage waters of the frontiers of British Guiana, the river-bed begins to broaden out and the slope decrease slightly. The velocity of the current at this point is 5 ft. per second at summer level. Following the slope of the valley the river runs practically straight ahead to its confluence with the Rio Negro, one of the main Amazon tributaries.

In this stretch of 400 miles all the phenomena of river flow can be seen in its natural state.

From the Mahu to Cachoeirinha the average fall is 4 ft. per mile. Here the river is obstructed by a large rapid, which is formed by the breaking up of an outcrop of rocks sloping in the opposite direction to current, of 2 miles extent and with a fall of 12 ft. in that length. The width of the river at the upper end of the rapid is 800 yards, and at the lower end 1000 yards. The banks are steep in places, and in summer weather 20 to 30 ft. above water level. The bed is strewn with boulders, between which the water rushes with a velocity of 10 ft. per second.

The river-bed from here to the Cachoeira Grande has an almost unvarying slope of 4 ft. per mile and a width of from 800 to 1500 yards. The second rapid is the greater, and much more extensive than the Cachoeirinha. It is from 2000 to 3000 yards wide and has only one unobstructed channel of a width of 40 yards, and in a length of 800 yards has a fall of 9 ft. The remainder of the river discharge finds its way through crevices of the rocks and boulders. From here onwards the slope becomes gentle, from 2 ft. to 1½ ft. per mile in a bed, the width of which varies from 800 to 2000 yards, between wooded banks, 30 ft. to 40 ft. above summer level.

The ratio of maximum to minimum discharge below the confluence of the Tacutu is 55 to 1, and at Caracarahy below the Grand Rapids, 95 to 1.

In the lower reaches of the river it was impossible to measure the maximum, as the banks were submerged for a great distance inland, not only owing to the floods of the Rio Branco but also those of its parent stream, the Rio Negro.

Throughout the whole of the length, at distances varying from 5 to 20 kilometres, there are large islands in mid-stream of about 1000 yards long and 100 to 200 yards wide.

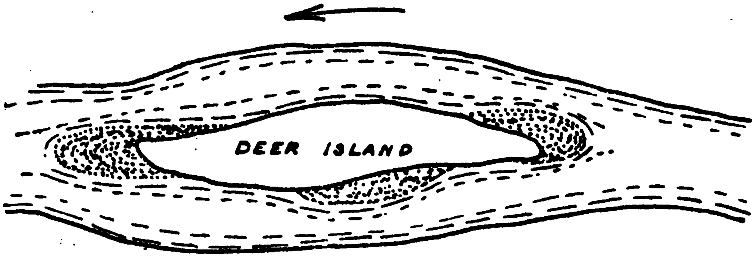


FIG. 27.

At the upstream end of the island there is generally a large sand-bank with a preponderance to one side or the other (fig. 27), and at the downstream end there is also a sand-bank, but more symmetrical, extending downstream in the form of a tongue.

In the dry season the river-bed is one mass of sand divided up by a comparatively small river zigzagging from side to side, and here and there broadening out into a shallow pool, apparently without natural arrangement.

A closer examination, however, reveals a very clear and impressive explanation of the seeming capricious wanderings. All the sand-banks have a feature in common (see fig. 28). The downstream edge is invariably perpendicular to the direction of the current, when the bed is running full, and is sloped steeply down to the bed (fig. 29). On the other hand, the upstream edge is curved into the current and has a gentle upward slope, as indicated in the figures. The slopes, as measured on the Rio Branco, were on the upstream surface 2 : 1000 and in the downstream face 1 : 2.

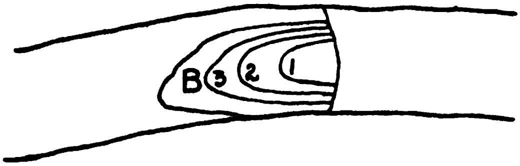


FIG. 28.

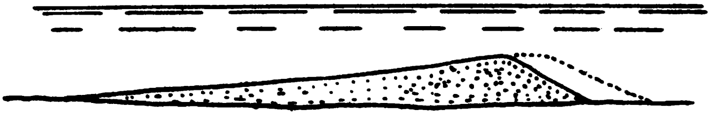


FIG. 29.

Another feature is the camber or hog of the vertical cross-section, being more pronounced at the nearer bank (see fig. 30).

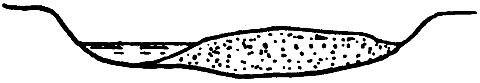


FIG. 30.

After several months of careful measurement, etc., the author came to the following conclusions :—

1. The sand-banks are continuous and progressive, or

that they are formed when the bed is running full and they then stretch from bank to bank.

2. The upstream surface forms an inclined plane up which the sand is rolled or rather pressed along in the manner of the very wet sand of a seashore when the incoming swell runs over it (see fig. 31, also plate V).
3. The progression of the bank downstream is a measure of the discharge of sand over the deep edge, as shown by dotted line in fig. 29.
4. When the river level drops the sand-bank forms a barrier and is attacked by the eroding current at its lowest parts, which are invariably near the banks, and a channel is formed just sufficiently large to take the discharge of the river when its level is equal to that of the bank.

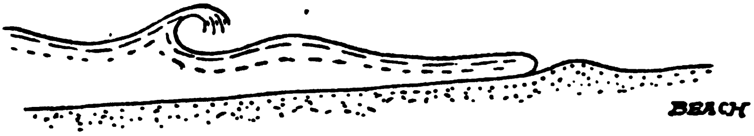


FIG. 31.

5. In no case does the river of its own accord break the barrier in the centre, leaving two sand-banks, one on each side. The channel is either under one bank or is divided into two forming a sand-bank in mid-stream.
6. When a sand wave barrier is broken at both banks the remaining island in mid-stream loses the characteristic of a perpendicular and steep downstream edge and becomes tongue-shaped (fig. 27).

7. The hogged or curved surface sloping down to the banks is due to the greater erosive effect of the current near the banks (see Chapter VII.; fig. 30).
8. The material constituting the sand-banks is not brought down from the hills of the source, but the greater portion is eroded from the banks.

The above general facts apply to all semi-torrential rivers, and in a lesser degree to smooth flowing rivers.

The Loire and the Garonne, in summer, meander about their beds, which are covered by banks of sand and gravel. The ratio of maximum and minimum discharges of these rivers have attained 200 : 1 in the case of the Loire, a ratio of 220 : 1 at Orleans, and 60 to 1 at Nantes: thus showing a great diminution of effect on approaching the outlet.

It is interesting to note that following a flood the French Government engineers made a careful survey of the amount of earth eroded from the river banks, and the following extraordinarily large figures were arrived at:—

Upper Loire . .	1,900,000 cubic yards.
Allier (tributary) . .	8,190,000 ,, ,,

The composition of the ground eroded was 70 per cent. sand and gravel in the Loire and 60 per cent. sand and gravel in the Allier, the remainder, being alluvium, was carried off by the current. Thus we see that in spite of the river-bed gaining an increased area of 3,500,000 square yards, over 6 million cubic yards of sand and gravel were added to the encumbrances of the channel.

Smooth Flowing Rivers.—The majority of rivers flowing through sedimentary strata are of the smooth-flowing type.

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PLATE VII.

A.—RIVER THAMES—THE CHERTSEY WEIR.

B.—A TYPICAL VIEW OF A THAMES LOCK—CHERTSEY.

To face page 56.

Their chief characteristic is that the basin has a large preponderance of permeable strata which regulates and maintains an even discharge. They are of small slope, and consequently low velocity, and follow a winding course.

The river Seine is one of the best known of this type, and flows through a basin of the following physical characteristics:—

Permeable strata . .	22,800	square miles.
Sloping impermeable strata,	3700	,, ,,
Flat impermeable strata .	3700	,, ,,

The flat impermeable strata is not so serious in the torrential effect as sloping ground of the same composition, since the waters do not collect so rapidly in the water-courses. The mean fall between Paris and Rouen is only 14 in. per mile.

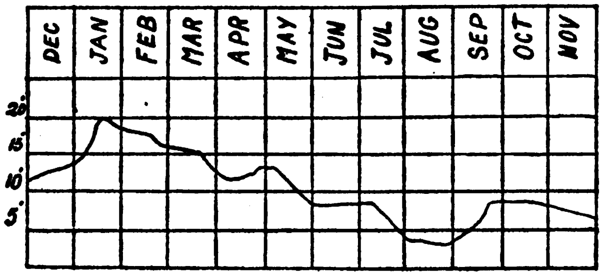

FIG. 32.

The river Yaco, a secondary tributary of the Amazon, furnishes much valuable information of this type of river in its natural state.

The discharge diagram of these rivers take the general shape of a wave curve rising gradually to a maximum and falling to a minimum in the same gradual manner (see fig. 32). Local floods produce a series of serrations on the average curve, depending on the discharge of torrential tributaries. The variations of discharge are not so great as in other types of river, and seldom exceed 30 to 1 in the upper valley, diminishing to as low as 6 to 1 at the outlet. The Mississippi and the Amazon have a ratio of 4 to 1 near their deltas.

The cross-section profile is symmetrical in the straight lengths of the channel and approximates to the broad V section, as in fig. 5. The river-bed is just sufficiently large to carry the average discharge, and this channel is maintained regular by the erosion and deposit, even though the river course may shift bodily to one side or the other, as in the hollow of bends, etc. (see Chapter VII.). The low velocity of the current not being sufficient to overcome obstructions, the river-bed often suffers great lateral movement in consequence.

The fluctuations of the water level being gradual, vegetation takes root to the water's edge and sometimes 2 to 3 ft. below it, thus affording a further protection to the river banks.

These rivers are very suitable for navigation, as the depth can be regulated and maintained economically without obstructing flood discharge.

At the points of inflexion of the bends shallowing is not so much in evidence.

CHAPTER VI.

FLOODS.

FLOOD control in the thickly populated European and Asiatic continents is particularly important, and is becoming so in the less peopled American continent.

As we have already seen, the amount of rainfall in a small catchment area may give us an approximate idea of the increased discharge that a river may be called upon to carry.

When we treat, however, of a large basin, which is drained by a large river and a number of tributaries running through different qualities of strata, the flood level becomes much more difficult to forecast from the rainfall. The times of the arrival of flood waters of a torrential and of a smooth flowing stream, of equal lengths, into the main river would naturally be in favour of the former.

As the tributaries of a river are at varying distances from the mouth, and as the rainfall is not likely to be equal in intensity and duration over the whole basin, the chances of the coincidence of the arrival of flood waters of all streams at one particular point are very small. However, it may and does happen that the ground is so saturated or frozen in the permeable strata that a continuous rain taking place in the basin may cause the flood waters to follow each other at so short an interval that the consequent rise submerges the banks and inundates the valley.

Generally, floods in the upper part of a valley do not cause much damage, and are sometimes, especially in the winter months, very beneficial to agriculture. On rivers such as the Seine, where great damage may be caused to property and navigation, a system of predicting the time of arrival and the height of floods at particular points has been developed.

The height and rate of rise of the floods in the tributaries and upper reaches is telegraphed to a central station, and there, with all data ready to hand, the engineers deduce the progress of the waters downstream. By this means due warning can be given to the population, and all valuables and perishable goods, etc., can be removed from the threatened area before the arrival of the flood.

So accurate has the forecast become, and so carefully have the observations been made, that the height of the waters can be estimated to less than an inch of their actual level, several days before the occurrence.

These results can be obtained for any river by compiling tables or graphs of different levels of the tributaries and the resultant effect upon the main channel.

The difficulties of flood control and protection are tremendous. In France the struggle has been waged for centuries, with varying success. The flood protection works of the Seine have been carried out with great skill, but even at date January, 1919, the following extract shows that the struggle is unequal, and that floods still cause havoc in the Seine valley.

"Yesterday's despatch from the Marne and Grand Merin forecasts that next Thursday the flood level at the Pont d'Austerlitz will be 16 ft. 8 in.; however, this will not be so serious as in 1910, when the flood level registered was 31 ft. 4 in.

To-day's measurements are—

Pont d'Austerlitz . .	14 ft.	2 in.
Pont de Tournelle . .	13 "	8 "
Pont Royal . . .	17 "	2 "
Bezons	16 "	7 "

Showing an average increase of 6 in. since yesterday.

On the upper Seine there is a diminution of 2 in., but at the confluence of the Marne there is an increase of 6 in.

The public bodies are now occupied with a scheme to heighten the quays, and several roads in the vicinity, deepening of the Seine channel, and control of the waters of the Marne."

No system has so far been inaugurated that can entirely prevent flood waters inundating the lowlands, excepting in small watersheds where large works of canalization have been carried out, as the Manchester Ship Canal. It must be borne in mind that the maximum flood is due to a series of abnormal circumstances, and that to reduce the resultant effects the cost of the works and their maintenance would generally be more than the damage likely to ensue from inundation.

A system of works to control the average flood would be quite adequate, and where there is valuable property endangered extra protection could be made, at the cost of the local authorities.

In the upper valleys the collection of the rain waters can be retarded by the afforestation of mountain slopes and by an extension of vegetation on all uncultivated waste and swampy ground.

The increased amount of systematic and scientific drainage of farms, and the paved streets of towns, cause a great amount of rain, which would otherwise be absorbed by permeable strata, to be conveyed rapidly into the nearest water-course.

The influence of torrents is felt very quickly in the main stream, and to counteract this serious state of affairs it has been proposed to impound the waters of torrential streams by forming large reservoirs in their valleys. The first attempt was made on the Upper Loire with indifferent success, as the volume available upstream of the dam is not sufficient to take the excess during abnormal floods. The town of St. Etienne downstream of the dam has, however, not been subjected to such severe inundations as were frequent prior to the construction of the dam.

The serious effect resulting from a restricted passage flood of waters is well illustrated by fig. 33, which shows the high level attained by the flood waters of the river Rhone in the Gorge of Pierre Chatel. Had the passage been wider, the water level would not have exceeded that shown by dotted line. This small diagram is sufficiently illustrative of the fact that the main requirement in the control of floods is a free and wide channel.

Levees.—The most successful treatment yet adopted is that of a system of longitudinal embankments or levees built back from the river bank at a distance of not less than the breadth of the river (see fig. 34).

Of the European rivers earliest mention is made of the embankments of the Loire in the 13th century, and since

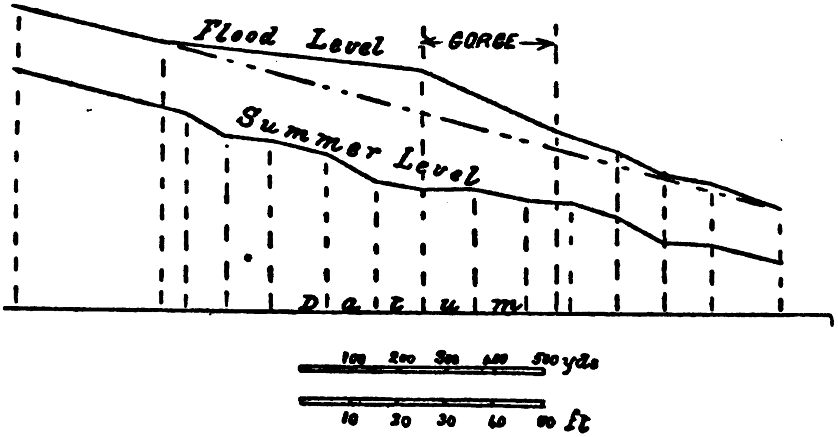

FIG. 33.

that date the Rhone, Loire, Garonne, etc., have had extensive works carried out to mitigate the floods. Many costly failures have occurred in their embankments due

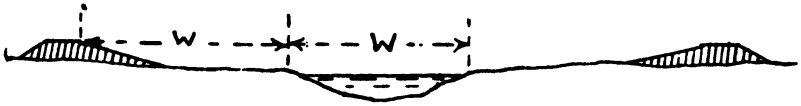

FIG. 34.

to a want of continuity and of foresight. In the construction no provision was made to relieve the pressure of abnormal floods, with the consequence that the banks were submerged and large breaches made by the inundating waters. The upkeep of these embankments has been enormous, and is several times greater than the benefits hitherto derived from them in times of average floods.

The few cases where embankments have been successfully used for many years a grave consequence has been the heightening of the river-bed due to the deposit in the channel, of alluvium which would otherwise have been spread over the valley.

The sum total of all the experiments points forcibly to the fact that a deepening of the channel and a clear river course, combined with a system of submersible embankments, is the most economical and durable system. The submersible embankments should be built at least three times the width of the river apart, and run as nearly as possible parallel but not necessarily following the windings of the river. Abrupt changes of width or curvature must be avoided, and the line of the embankment must not approach nearer than 50 yards of the river bank (see fig. 35).

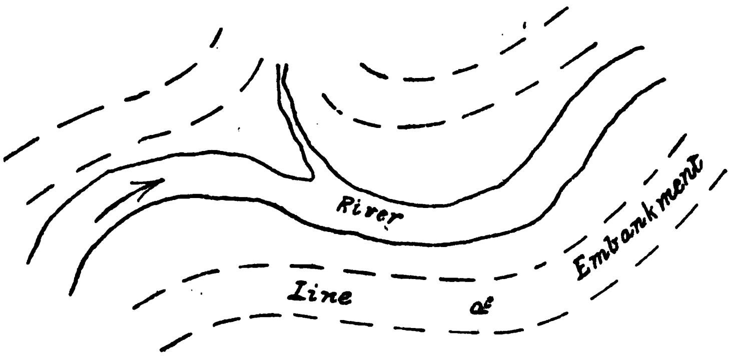

FIG. 35.

The embankments may be constructed of earth or sand (fig. 36), or of patent "UNIT" concrete construction with earth backing (fig. 37).

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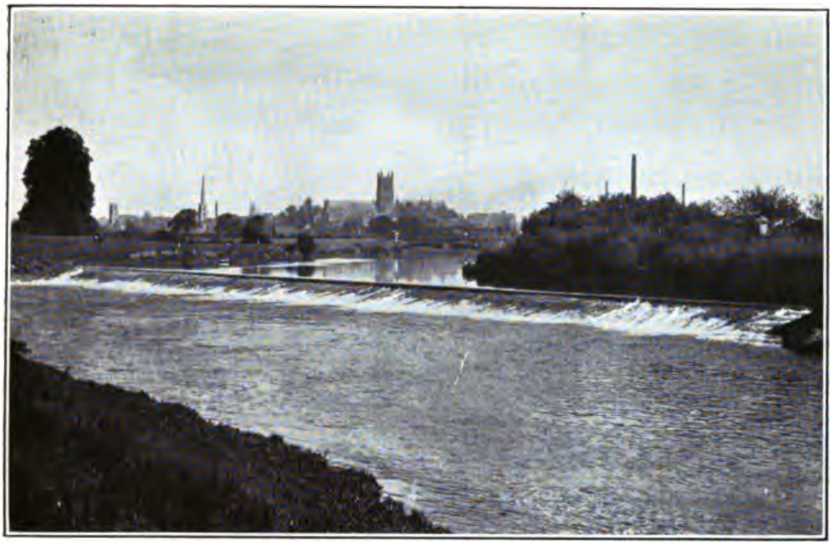
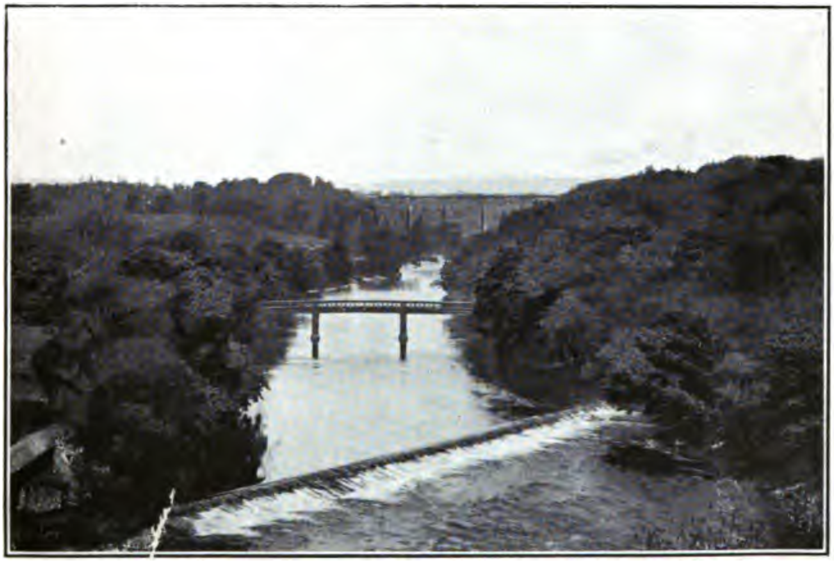
PLATE VIII.



A.—OBLIQUE WEIR BETWEEN LOW BANKS—RIVER SEVERN.



B.—OBLIQUE WEIR BETWEEN HIGH BANKS—RIVER TEES.

To face page **64.]**

The general care in the construction of the embankment has to be taken, such as building up in well-trodden layers and protected on the river-side by a tough soil or clay. Where a high velocity of current is likely to occur, an increase of width of embankment is preferable to spurs.

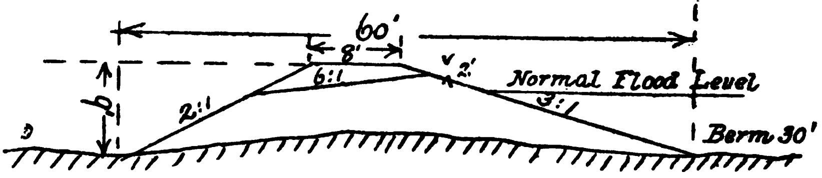


FIG. 36.

At intervals in the length openings 1 ft. deep below crest are built in and pitched to a depth of 15 in., both slopes being protected for a distance of 5 yards downstream and on the river upstream side for 10 yards, 1 ft. above and 2 below river-flow level.

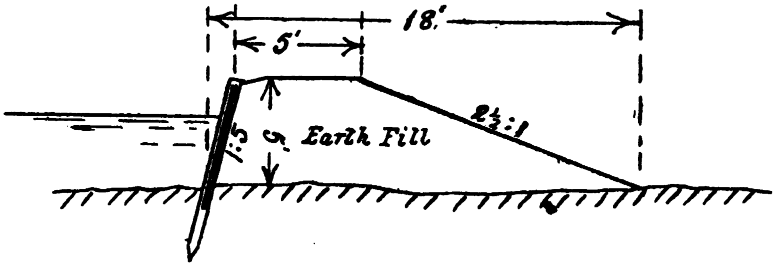


FIG. 37.

The width at base of the embankments varies from six to eight times the height, the former for small and the latter for large, embankments.

The type of levee most common in America is that shown by figs. 38 and 39. Where the sides are exposed to wash of the current entering from a tributary they are protected by fascine mattresses.

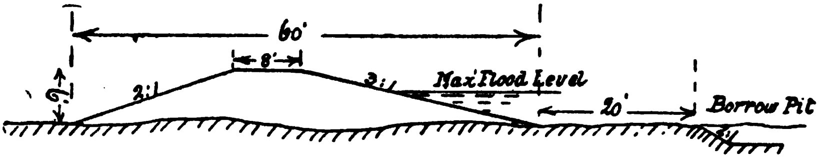


FIG. 38.

Borrow pits for the construction of the levee should not be more than 3 ft. deep, and should be at least one-third the maximum width of embankment from the toe, on the river-side. They should not be continuous, but

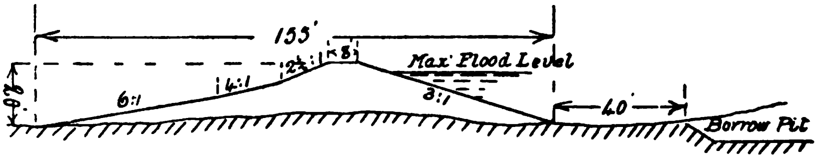


FIG. 39.

dug in the manner of pockets, leaving a berm of at least 10 ft. wide between them—as in the case of borrow pits for railway embankments.

The maximum flood discharges are naturally greater per sq. mile in a small watershed than in a large watershed. Thus, a tributary of the Rio Grande, Brazil, of 60 sq. miles drainage area discharges in flood 120 cubic ft. per sec. per sq. mile, whereas the parent river draining 6500 sq. miles discharged only 16·5 cubic ft. per sec. per sq. mile during the heaviest flood.

CHAPTER VII.

WATER FLOW.

THE cycle of changes wrought by running waters is nowhere more plainly observable than in the Amazon tributaries.

The incessant steady flow through a sedimentary strata and over shifting beds facilitate a close study of the phenomena.

In a straight length of channel where the water is shallow near the banks and merely laps the sides a series of small terraces are formed, as at fig. 40 at *a*. Where there is a steep bank of clay, and where the water level remains more or less constant for some time, the water scoops out the bank in the form shown by fig. 40 at *b*, and eventually the overhanging mass will fall into the river-bed, and there be graded and transported by the current according to its weight and size.

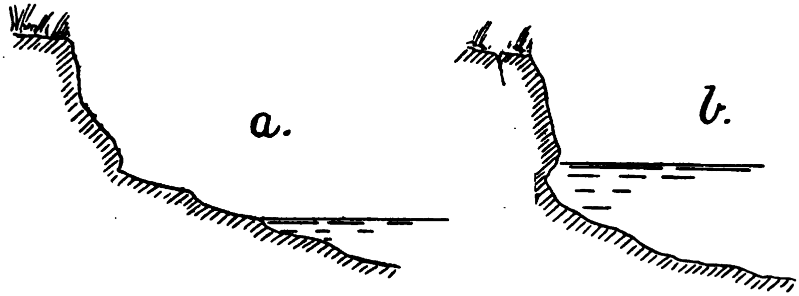


FIG. 40.

In a previous chapter it was shown that the maximum velocity was about mid-stream and along the deepest longitudinal section, and that the minimum was at the banks. It is therefore clear that the river-bed has a very great retarding effect upon the velocity, and particularly so as the water becomes shallow. As the whole surface has the same amount of contact with the air the drag near the banks must be due to friction on the sides. Therefore the water at the edges uses up the velocity it should have, due to the fall, in rubbing away the banks, and is for that reason incapable of transporting material along the bed. This latter fact is particularly noticeable in the formation of sand waves, as already pointed out in Chapter VI.

The transporting power of water is as the sixth power of its velocity or—

$$T \propto V^6$$

Thus if the velocity is reduced by one-half the material it is capable of transporting is sixty-four times less than before.

One is apt to forget this large variation, in practice, and therefore not appreciate the extra work that can be accomplished by a very small increase in the velocity of the current.

Erosion.—Every one must have noticed how at the river's edge the water laps the bank; this is not due solely to wind, but is due also to the drag of the current, and on a calm day on both sides of the stream the progress of these miniature waves bears a direct relation to the direction of the current.

Should the level of a stream fluctuate the erosive effect of these current eddies is not noticed, but if the level remains fairly constant they are capable of causing a great deal of damage to an unprotected bank, as seen in fig. 40.

The eddies at the water's edge are often aided by the wind, and small wavelets are formed which attack the bank, and on a windy day one can often notice that the water near the exposed bank becomes as a consequence muddier than usual.

On all banks having a gentle slope, the water's edge in plan presents a wavy line, due to a progressive action of erosion and deposit.

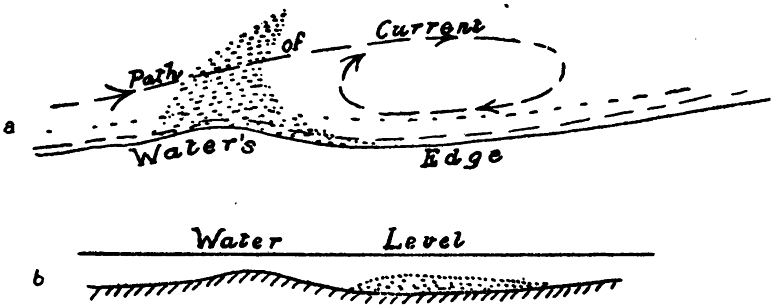


Fig. 41.

Thus in fig 41*a*. the currents set up locally near the edge are shown by the arrows. This reversed current is caused by a slight hump and a slight hollow shown in profile in fig. 41*b* (along the heavy line).

The slackening off in the velocity downstream of the hump causes a deposit in the hollow, and this continues until the hump transposes itself, when the same process goes on downstream, and so on down the river, all the material being provided locally from the banks, and being very fine sand or silt. This fact is particularly important, as the principle is exploited to a great extent in practice.

These reversed currents or dead waters are very common on the shallow Amazon rivers, and are known by the natives as "remanses." They vary in size from a few feet to 150 yards long.

Trees falling over into the river-bed are often the cause of large remanses, especially if the river is burdened heavily with silt.

The river Yaco has several times had tremendous lateral movements caused, in the first place, by trees tumbling over into the river-bed and forming a system of groynes or spurs, which caused a deposit locally and concentrated the waters upon the opposite bank.

The above phenomena are not peculiar to natural water-courses, but is in evidence on trained rivers, canalized rivers, and canals where the waters have a regular velocity.

Transporting Power.—It is obvious that at different velocities different materials may be carried, as for example—

Vel. feet per second.	Material.
0·26	Silt
0·50	Fine sand
0·75	Coarse sand
1·00	Gravel (small)
2·20	„ 1-inch sieve
4·00	Heavy shingle, etc.

In flowing through strata yielding these materials it follows that the water will transport such as its velocity is capable of. Thus it behoves the engineer to reduce the influx of detritus into the channel to a minimum, and to so protect the banks that the velocity of the current is utilized in preserving a regular depth by concentrating its power of transport upon the material already encumbering the bed.

Silting cannot be entirely stopped, for even in canals the bed becomes covered with deposits which are ofttimes of great volume. A case in point is the Manchester Ship Canal, which yields 1000 cubic yards of deposit per square mile of watershed per annum.

The ideal condition is that the water may be self-maintaining, and that sufficient velocity is maintained throughout to keep the detritus constantly in motion.

The sum total of all facts is to reduce detritus to a minimum by the protection of the banks and the maintenance of a free passage in a regular channel.

Works of partial and local treatment are never successful. All undertakings should be comprehensive and general. The river should be modified as a whole to obtain a maximum efficiency, and, in the long run, a minimum of cost.

Flow Round Bends.—The least understood of all river phenomena is that of the flow round bends and the action of the water in its passage.

The general facts are—

1. There is an increasing deposit on the inner or convex bank (figs. 42 and 43).
2. There is constant erosion on the outer or concave bank (figs. 42 and 43).
3. That the radius of curvature tends to decrease (fig. 1).
4. That the greatest depth is under the concave bank.

The soundest explanation of the phenomena has been made by Hunter in his "Rivers and Estuaries," where he advocates the theory of Professor J. J. Thomson.

The professor carried out a series of experiments in a channel shaped as in fig. 44, and with the aid of seeds and drops of aniline dyes he was able to fix the direction of the currents set up. These are indicated in the figure.

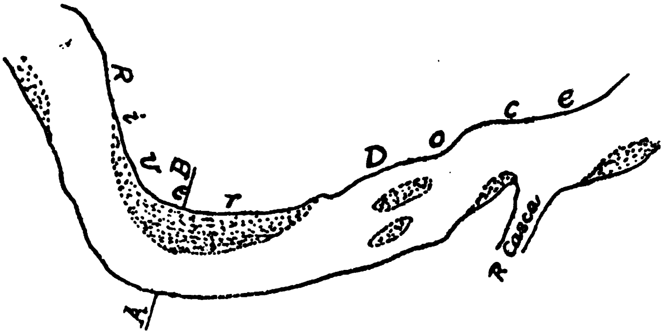


FIG. 42.

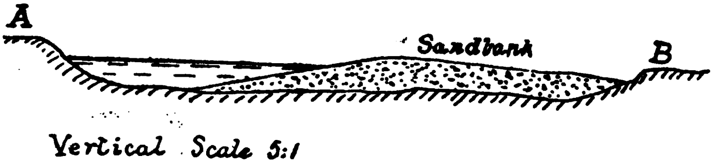


FIG. 43.

His contention is that the centrifugal force of the waters cause an increase of level on the outer bank, and that transverse currents are set up on the river-bed which mount the inner or convex bank (fig. 45). The deposit of the material on the inner bank and the eroding of the outer bank is therefore due to these transverse currents.

Professor Thomson also concluded that the maximum velocity was on the inner or convex bank.

There can be no doubt that the above conclusions are applicable to permanent channels of regular cross-section, but when applied to a natural water-course they are modified to an appreciable extent, depending upon the shape of the river sections not only in the bend but above and below, and also the degree of mobility of the bed.

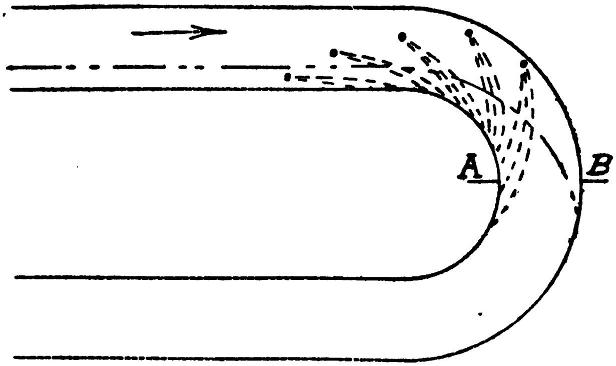


FIG. 44.

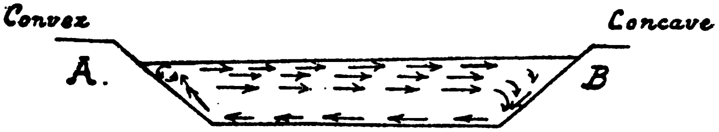


FIG. 45.

Fig. 46 shows a plan of a reach of the river Yaco, from which it can be seen that the deposit on the convex bank is evident before the centrifugal force of the waters could produce the transverse currents, and that the deposit is general around the whole curve until the point of inflexion of the next bend is reached, where it shifts over to the other bank.

The deepest part of the river is shown by the darkest shading, and a curious fact is that the deepest point is not in the summit of the curve but downstream of it.

Similarly, the highest deposit instead of being at the apex of the curve is also downstream, and more or less parallel and opposite to the deepest section.

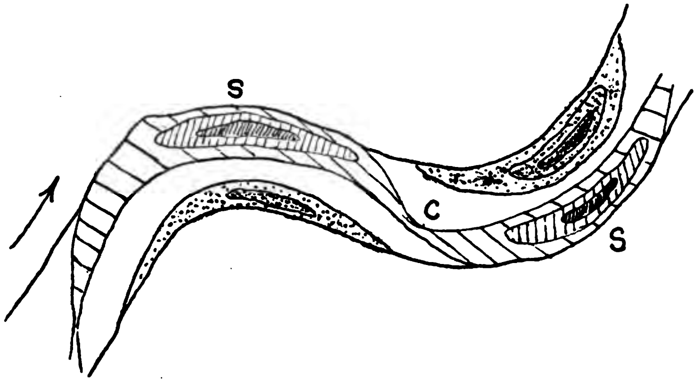


FIG. 46.

The velocity of the current attains a maximum between the concave or outer bank and mid-stream in this particular instance at one-third of the width from outer bank. This disagreement with the professor's conclusion is only apparent, as the shape of the bed and the thalweg and the mobility of the bed modify the theory.

The line of maximum velocity depends upon the curvature and the following instance (fig. 47) of the Rivers das Velhas, Minas Geraes, Brazil, will illustrate very clearly that in practice the most important factor is the direction of the approaching current and not the centrifugal force. In the figure the maximum velocity was directly under the concave bank, and a large whirlpool was formed just downstream of the summit of the curve.

This river has a very sinuous course, and at the point in question known as Poço Feio or Ugly Hole there is a very sharp curve which causes a tremendous disturbance of the waters, productive of strong eddies which scour out the bank and bed and whirl off the debris downstream.

The notable feature is that the deposit does not begin as far upstream of the apex as in the former case, and that it grows quite large downstream, where there is a "reverse" current. The explanation of the first point is that the deposit does not take place until the direction of the current tends to leave the inner bank and finishes where the general direction of the current again meets it, after being deflected by the outer bank.

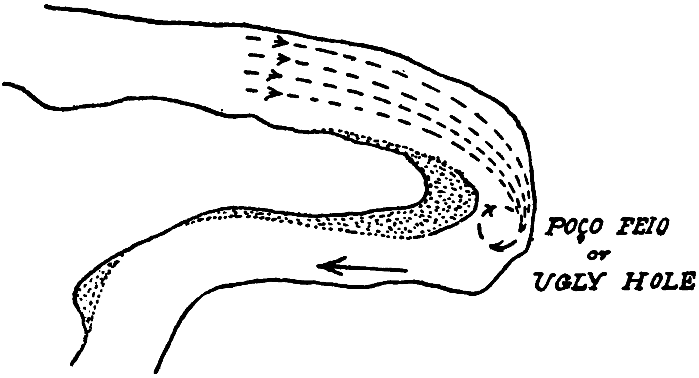


FIG. 47.

The predominating fact is that the greatest depth is always in proximity to the greatest resistance to the flow of the water, and is due to the increased local disturbance consequent on the waters being deflected from their original path.

As the greatest erosion is always downstream of the summit of the curve, the tendency is for the bend to travel downstream.

The above notes of actual facts emphasize the weakness of theorizing on the flow of rivers, and the engineer who tackles river problems for the first time must study the particular case with the greatest care, and find his own facts.

CHAPTER VIII.

RIVER TRAINING.

The broad principles of river training are in themselves extremely simple, but their economical application to particular rivers becomes increasingly difficult as the variations of the discharge become greater.

The semi-torrential class of rivers are more troublesome than smooth flowing rivers, and less than torrential.

The most important factors in the regime of a river are that the general width should gradually increase as it progresses, and that it should be so regulated that the waters have a free passage and that the transport of the detritus be constant throughout the whole length. There should be no sudden increases of width, as these promote deposit and cause the channel in the dry season to meander about the bed ; similarly, there should be no narrow passages (see fig. 33), as then the bed is scoured out and the velocity of the current may become prohibitive owing to the heading up. The banks should therefore be protected and trained with the double purpose of preventing erosion, and at the same time concentrating the transporting power of the waters upon the preservation of the river-bed at the required depth.

At bends, suitable precautions will have to be taken to direct the waters in such a way that the maximum advantage may be derived from them, for they are then in a more destructive state than when in the straight reaches.

The effect of imposing any obstruction to the regular flow of the current causes a great local agitation, and from the careful observance of this phenomenon we can formulate the following rules:—

(i) Any obstruction jutting out at right angles to the bank causes reverse currents to take effect at about half its length from the bank, and causes deposit in the manner shown in fig. 48.

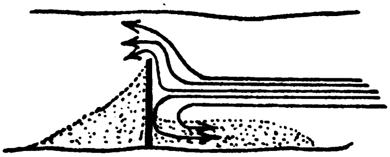


Fig. 48.

(ii) Obstructions at an acute angle to the bank cause reverse currents to form nearer the outer extremity, and cause deposits as shown by fig. 49.

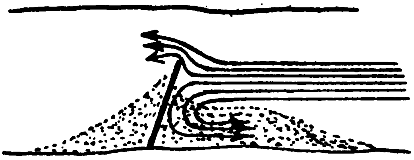


Fig. 49.

(iii) Obstructions at an obtuse angle to the bank (fig. 50) tend to divert the current to the opposite bank, and as a result great internal movement about the obstruction causes a scouring of the bed along the line of resistance, and no deposit takes place.

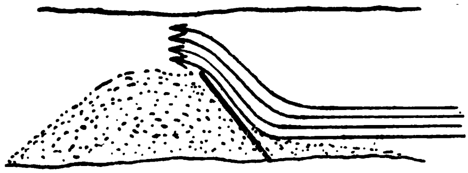


Fig. 50.

A very sound indication of the value of oblique obstructions in the scouring out of a channel is the fact that the naturally deep channel is always to be found along the concave bank.

The obvious method of promoting an increase of depth and impeding the formation of shoals is to narrow the width of the channel, but great care must be exercised, as there is a limit to its advantages.

Should the river be narrowed beyond the average width suitable to the discharge there will be a scouring of the bed locally, and a diminution of available depth in the neighbouring reaches, which may result in a greater impediment to navigation than the original shallow.

The width of the river at the summit of a bend should not be lessened excepting in the case of easing up any irregularities in the curvature of the concave bank. In no case should the convex bank be advanced into the stream.

A river bend with protected banks will always preserve its deep channel, and any regulating of width would entail unnecessary expense.

Generally when there is an island in the river-bed only one of the two channels is navigable, and that is usually the one with the greatest curvature. It is therefore advisable to link up the island to the convex bank with a low-water training wall (see figs. 51, 52), and thus concentrate the flow along the concave bank in the summer and leaving the channel free passage for flood waters only.

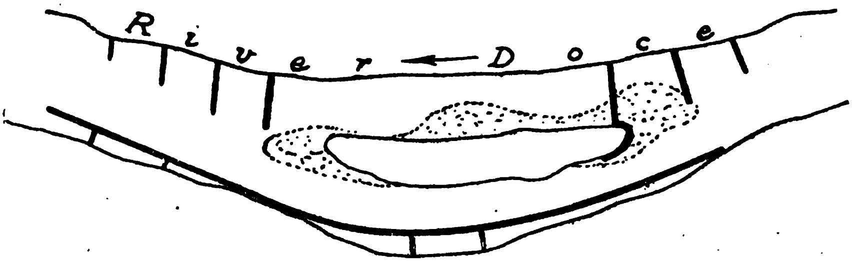


FIG. 51.

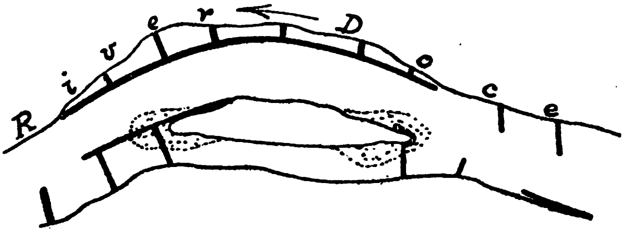
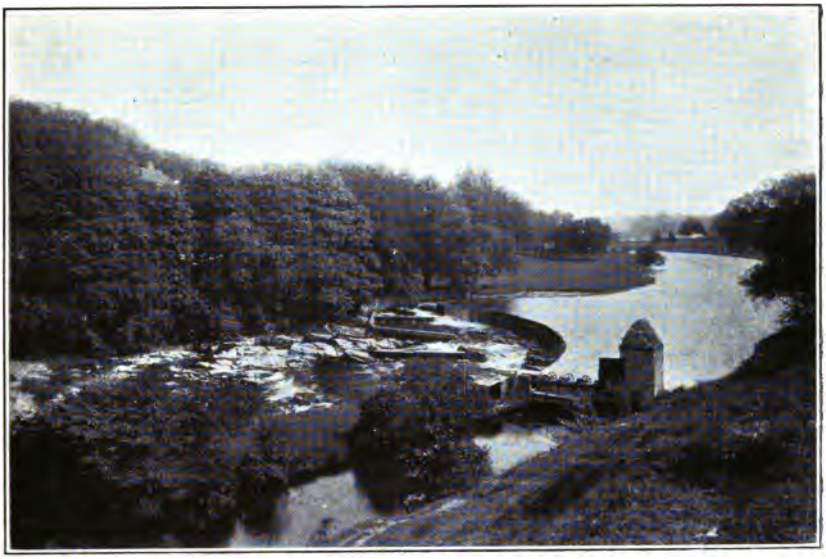


FIG. 52.

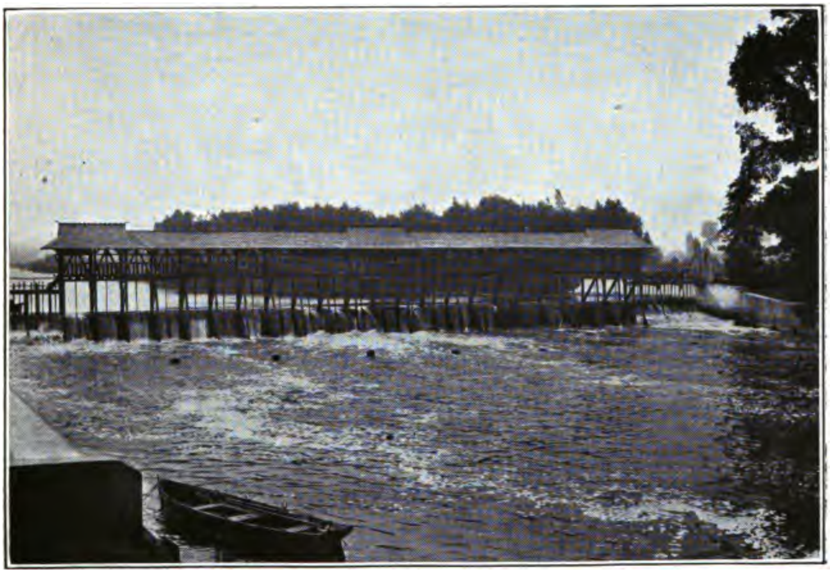
The success of all training works depends upon the condition that the regulation is only just sufficient to maintain the debris in motion, and therefore a stable bed.

In fig. 53 between the two deep sections at SS the river runs obliquely across the channel, and thus spreads out over a greater width normal to the current than the actual width of the river-bed. The consequence is that there is a bar or shoal formed at the point C.

PLATE IX.



A.—CIRCULAR WEIR AND CANAL INTAKE SLUICE—RIVER WYE.



B.—RIVER THAMES—THE BELL WEIR.

To face page 80.]

The majority of shallow rivers are rendered unnavigable on account of the large number of these shoals at the points of inflexion of the bends, and hence it becomes imperative that some permanent cure for the trouble should be undertaken.

As the tendency of the water is to cling to the concave bank and preserve the channel constant, the required depth at C should be obtained by a modification of the width.

As C is the shallowest section, it should also have the minimum width, and as the depth gradually increases from C towards the summit of the curves, the width should vary in the same proportion. Applying this principle to a double bend of the Rio Doce (fig. 53), we see that it will be necessary to undertake works represented by the hatched portion.

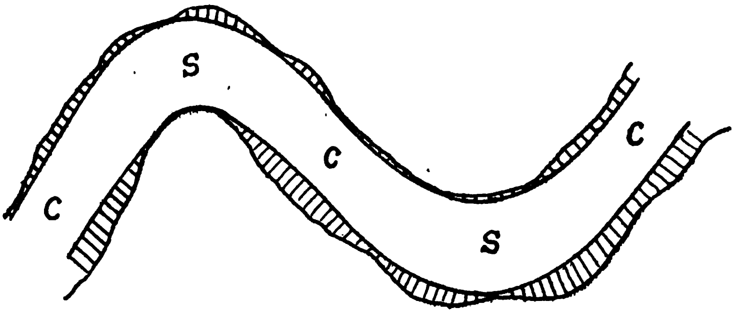


FIG. 53.

The cost of such works is very great, especially in large rivers, and for that reason its use is restricted to small canalized rivers. The same principle is adopted on large rivers, but the works take the more economical form of spurs and groynes. The ratio between the width of the stream at the points S and C varies according to the distance apart of the summits, and in no case should the width at C be less than four-fifths width at S.

The combination of short training walls and groynes is the most economical and practical method, since not only can the work be more expeditiously carried out, but the maintenance is much less costly than with continuous training walls.

Fig. 51 shows the principle applied to the Rio Doce, where at the bifurcation of the river-bed a groyne is built from the bank with the flattest curvature to the island at the upstream extremity, and from the same bank groynes are run out to a distance such that the free passage between their extremities and the opposite bank will cause just the necessary scour to maintain the required depth and uniform section.

As the waters are forced to leave the right channel of the river and flow through the left an increased amount of scour will take place, and to avoid erosion under the concave bank it is necessary to run a training wall throughout the length of the channel. The tendency for the bend being to travel downstream, the training wall may be commenced at some short distance below the commencement of curvature, depending upon the set of the current at the entrance to the channel. The downstream end of the wall, however, must be run out sufficiently far that the direction of the flow will not strike the outer bank, but will be deflected to the opposite bank.

The groynes (see figs. 52 and 54) should be placed at a distance apart not greater than 1⅓ times the required width of the new channel. And a line through their stream extremities should be parallel to the proposed direction of channel. The upstream end of the island should be protected by a heavy pitching, which should continue for at least 40 yards downstream of the nose.

No protection is necessary to the convex bank of the island unless the increased discharge of the channel, in the first flood after the modification have been carried out, will be such that the velocity of the rising waters will be above the critical velocity of the material of the banks. To avoid this the groynes and dam in the right channel should not be built at a greater height than 6 in. above averages summer level, but the training wall on the concave bank must be at least 3 ft. above this level. Several low training walls and embankments have been destroyed due to the non-observance of this rule.

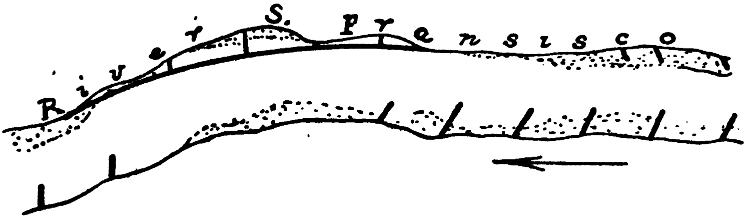


FIG. 54.

Comparing figs. 51–54 it will be noticed that the inclination of the spurs to the bank is different in each case, being more pronounced in the straighter portions of the river, and becoming more normal as the curvature increases. A good principle is to place the groyne at an angle of 75° to the direction of the current.

When a broad, shallow channel at a sharp bend, as fig. 49, has to be trained, the best plan is to advance the concave bank and build low submerged groynes on the apex of the convex bank with a low, short training wall just upstream of the point of inflexion.

A large semi-torrential river, such as the Rio San Fransisco, is best regulated by the system of groynes and bank protection, shown in fig. 51. The spurs or groynes in this case should have a slight slope towards the river-bed at their stream ends, so that the scouring of the river-bed will not be so violent as would happen if they were of a regular height.

It is not necessary to place the groynes on each bank exactly opposite one another nor yet at the same distance apart, as economy being the main factor in all works advantage must be taken of all natural prominences, as a base for the spurs.

Construction of Groynes, Training Walls.—The general European types of construction are those shown by figs. 55, 56 and 57. They are very costly, and can only be undertaken when large funds are available.

The type shown in fig. 55 is the cheapest and most easily constructed, being a rock-fill with hand-packed facing. The junction at the bank should be 3 ft. higher than the general level, and extend for at least 10 yards into the old bank.

The type best suited for the tidal reaches of the rivers, or where there is a large amount of traffic, is that of fig. 56.

Fig. 57 shows a section of a submerged wall constructed of faced rubble and strengthened by piles which extend 6 ft. above the apex so as to indicate their position to shipping. At the junction with the old bank there is a double row of piles boxed up with sheeting and clay-filled.

The types of groyne are merely modifications of these figures, the commonest being that of fig. 55.

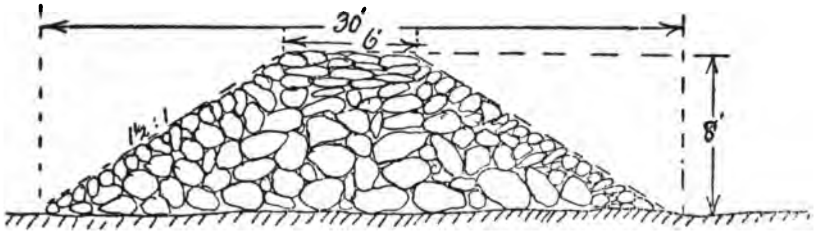


Fig. 55.

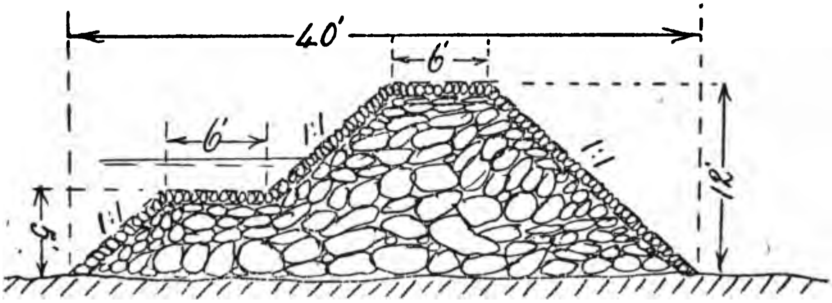


Fig. 56.

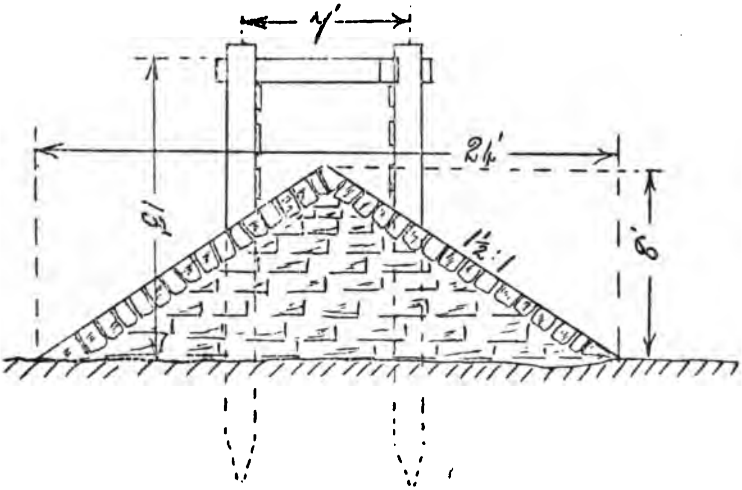
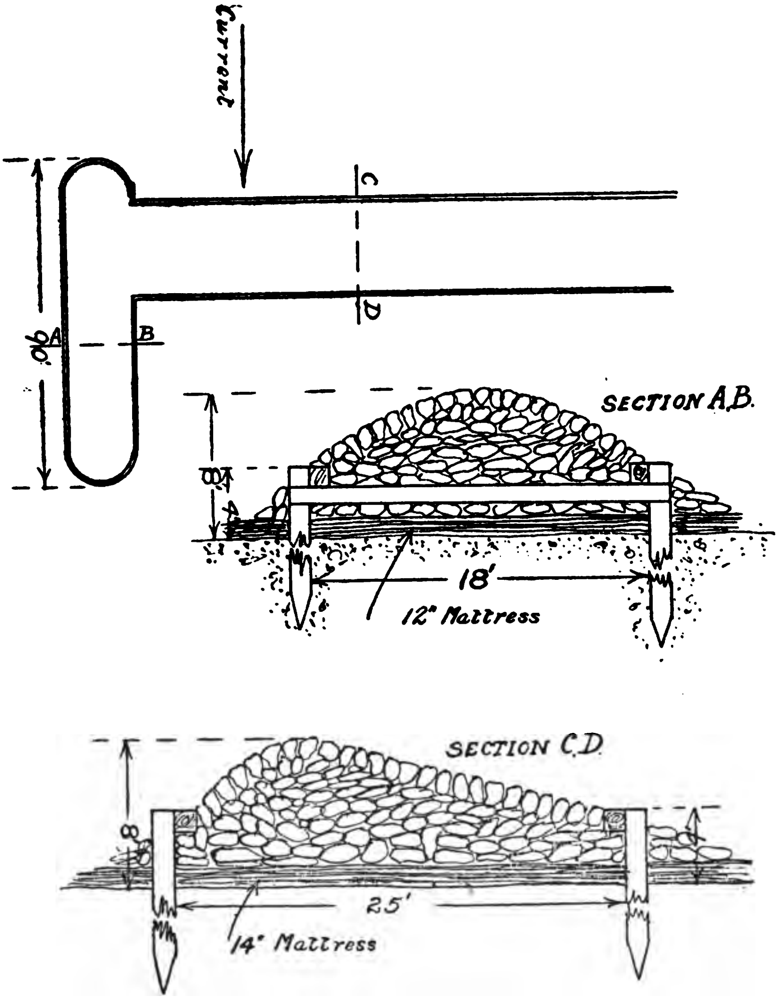


Fig. 57.

The extensive training works of the Ohio river have been mostly constructed of heavy rock-fill spur dikes as indicated in figs. 57*a* and 57*b*. Piles 12 in. diameter are driven into the bed in two rows from the bank, 25 ft. between each line with the piles spaced 6 ft. centre to centre. The tops of the piles are at low water level, and are all connected by 12-in. square waling.



FIGS. 57*a*, 57*b*.—ROCK-FILL SPUR DIKE, OHIO RIVER.

The spur (fig. 57*a*) is 90 ft. long and 18 ft. wide, having the piles spaced at 5-ft. centres.

On the bed of the river a 14-in. brush mattress is laid, and then the whole filled in with heavy rubble. Timber, being cheap in this locality, the cost of construction was not greatly increased by the lavish use of wood.

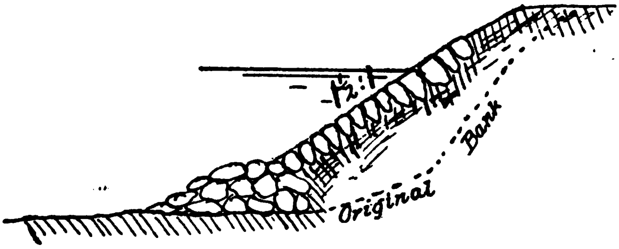


FIG. 58.

The protection of the bank resolves itself into pitching the face with stone, as in fig. 58, or a more expensive but very durable facing is that of fig. 59. Concrete piles are driven in to a height of 1 ft. below water level, and concrete slabs inserted in grooves between them. Their tops are connected by a 3-in. × 6-in. horizontal spar, which serves as a foundation for the stone pitching.

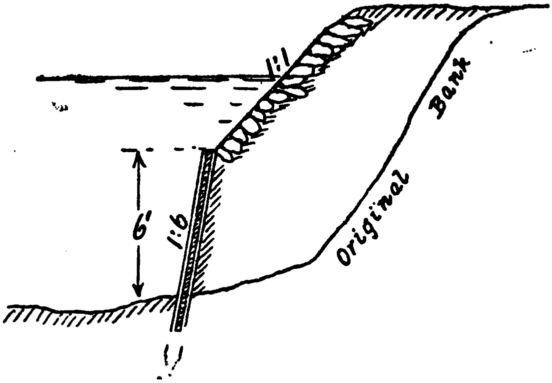


FIG. 59.

Fig. 60 shows an excellent and economical type of concrete mattress. In new undeveloped countries such as Brazil, broad, shallow rivers are the only existing means of communication for heavy traffic, and to make river training effective a much more economical system is essential. Hitherto navigation of these rivers has been restricted to short periods of the year on account of the many difficulties due to shoaling, etc., in the dry season.

To lessen the difficulties the author was entrusted by the Brazilian Government with the task of drawing up a scheme of economical river training, of which the following forms the basis, having especial reference to the river Branco in the Amazon valley.

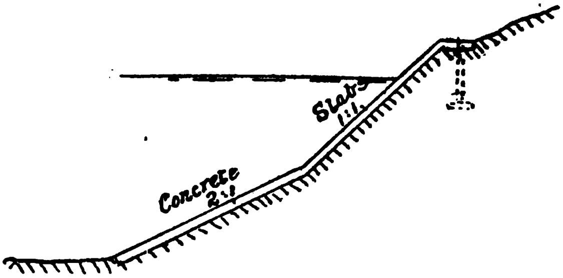
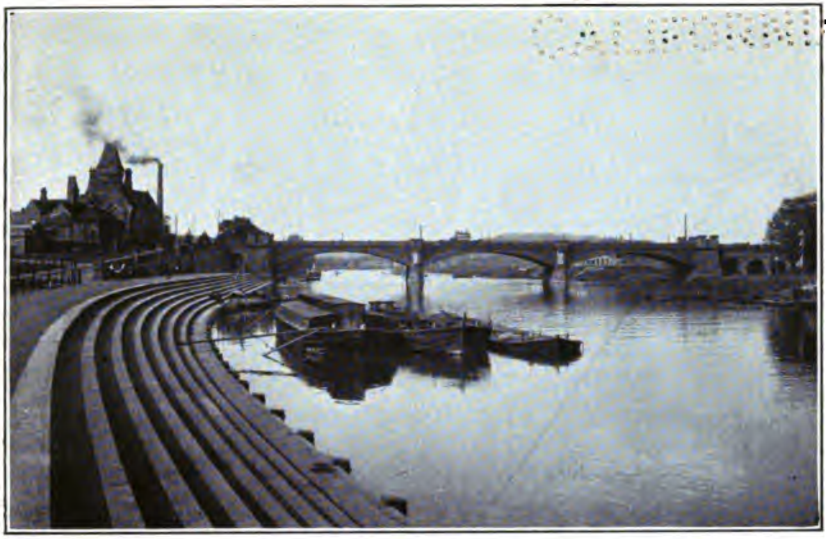


FIG. 60.

As pointed out in Chapter V. torrential and semi-torrential rivers carve out a sinuous channel in the dry season between the sand or gravel waves commonly found in the major bed. This channel is not permanent, but shifts about from year to year, and even in shorter periods depending upon the position of the detritus waves at the critical level of the waters. As the flow at low level has a preference for a winding channel, and that a greater

PLATE X.



A.—RIVER TRENT—A WELL-PROTECTED BANK.

B.—CANAL DOCKS, MANCHESTER.

To face page 88.]

depth of water can thus be maintained in the dry season, it follows that the undertaking should follow the natural lines as closely as possible.

The problem therefore resolves itself into preserving or fixing the position of the sand waves without retarding their progress. The method devised is shown by fig. 61.

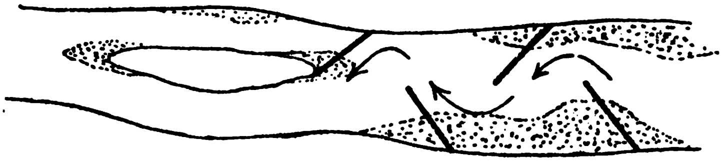


FIG. 61.

The groynes are run out from the bank, through the centre of the sand-banks to a distance depending upon the average discharge in the dry season. They are sloped at obtuse angles to the current, the toe of one being about 50 yards upstream of the heel of the other. The construction is extremely light, after the pattern of figs. 62 and 63, and they are sunk in the sand with their tops flush with the height of the crest of the sand-bank.

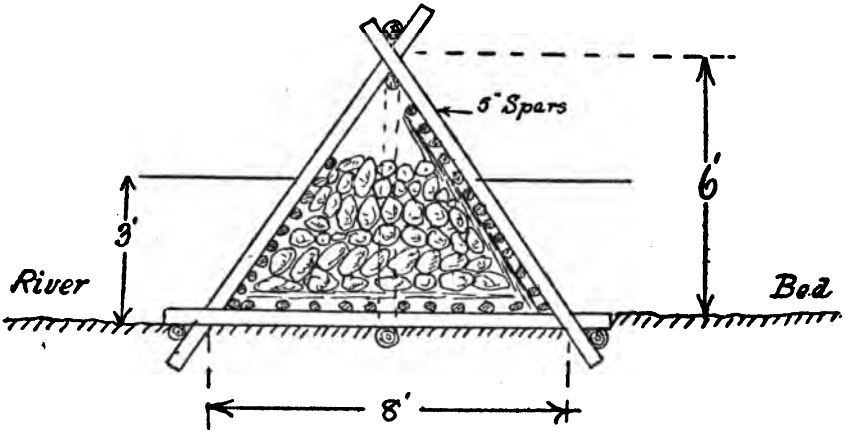


FIG. 62.

The cribs are constructed of 3-in. to 5-in. diameter poles of varying lengths, and the lattice made with "cepó" creepers on which grass is woven.

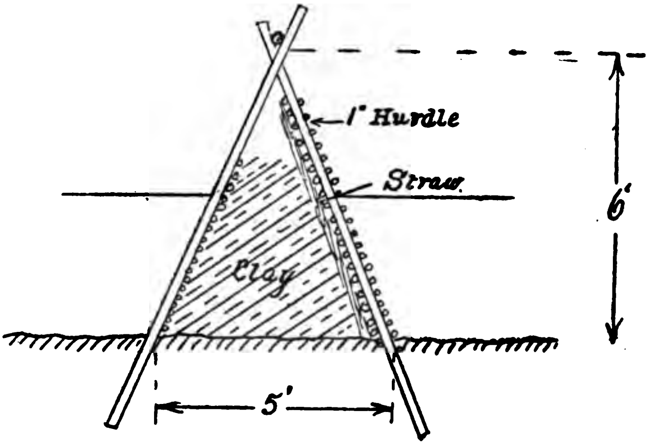


FIG. 63.

This type of structure and method of training is very rapidly accomplished at low cost, and the encumbrance of the bed is practically nil.

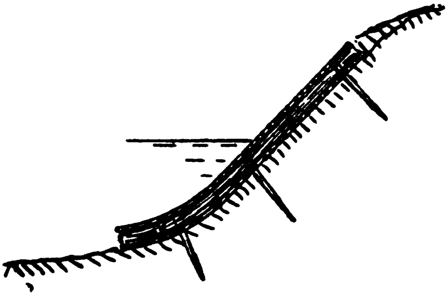


FIG. 64.

A good fascine mattress for the protection of the banks can also be made, as fig. 64, by sandwiching a layer of grass, etc., between two woven hurdles or lattices and spiking them to the bank.

The construction of large fascine mattresses *in situ* has been greatly developed on the large American rivers.

A large barge of small freeboard is fitted out on deck with a number of inclined launching ways, as in fig. 64*a*. They are spaced 5 to 6 ft. apart, and have a slope of 8 : 1. On these ways the brushwood is first bundled by strong wire in the cavity on the horizontal portion and then shoved down to the lower end of ways.

After a number are well bound together, 30 to 40 ft. cross poles are then lashed to the upper surface at 4-ft. spacing. On completion of a portion equal to the length of ways, it is partially launched and another portion added. In this manner enormous mattresses of several acres in extent have been built up. The sinking of such large and frail bodies in a strong current requires much care and resource. The best practice is to first sink the upstream edge, beginning at the corner nearest the bank and loading with stones diagonally across mattress, and not parallel to the edge. The floating portion must

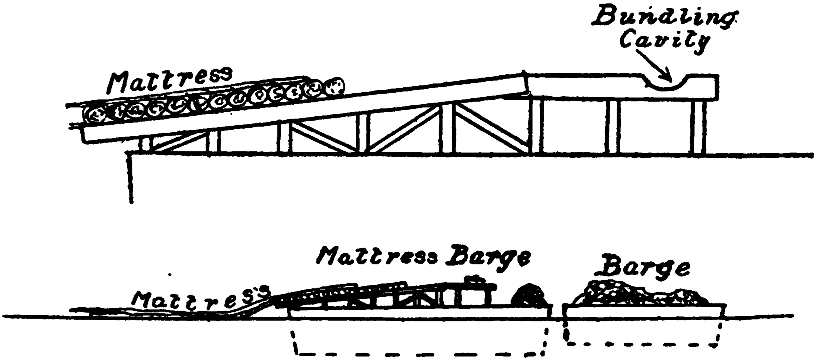


FIG. 64*a*.—FASCINE MATTRESS CONSTRUCTION BARGE.

meanwhile be kept securely moored so as not to drag the sunken part along the bottom. By proceeding in this wise mattresses can be sunk successfully in 100 ft. of water.

Submerged Groynes.—The carrying out of training works often necessitates a protection of the river-bed against undue scour, and this can be effected by mattresses of concrete slabs, or submerged groynes. The latter is the most practical for river work, and the former is more adapted to canals.

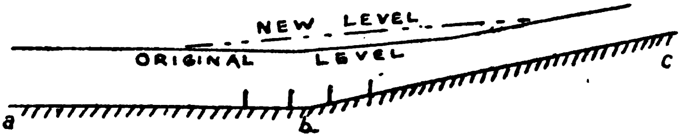


FIG. 65.

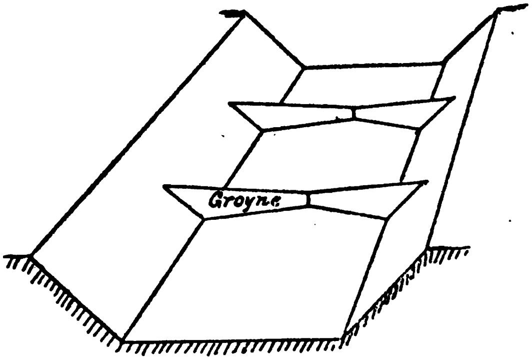


FIG. 66.

Fig. 65 shows at *ab* a deep channel of small slope, whereas at *bc* there is a shallow channel of greater slope. To regulate and equalize the depths without altering the available depth for navigation in the deep channel cross dykes (fig. 66) are built from the bank to mid-stream at an angle of 80° to the current (from the bank) and meet in the centre. The height of the dyke is a minimum in the centre, rising to a maximum at the bank.

The effect upon the water level is shown by the dotted line, and they further have the advantage of concentrating the waters into the centre of the channel.

They have been very largely used in the regulation of the river Rhone and German rivers, especially downstream of rapids or reaches of high velocity, and have proved very effective.

It is not good practice to ease bends by straight cuts through the convex bank other than in the most exceptional circumstances, or where the fall is slight, not greater than 10 in. per mile, as the greater velocity due to the increased slope will be productive of shallows in the neighbouring reaches, and incur expenses for bank protection in the neighbourhood of the works.

CHAPTER IX.

CANALIZATION OF RIVERS.

Until late years canalized rivers have been mostly of the smooth flowing type, due to the difficulties of providing suitable weirs for the rapid discharge of flood waters. With the introduction of movable weirs, however, canalization has been extended to semi-torrential rivers, and will soon be further made use of with torrential rivers.

There is no doubt that canalization should be more usefully applied to the torrential type than any other, in the interests of navigation, as not only is the water level maintained more or less constant, but the velocity of the current is considerably less and offers no impediment to upstream navigation.

The most important factor in this connection is the cost, for generally the slope of the torrential type of rivers would make it necessary to have short reaches. In smooth flowing rivers, such as the Seine, the weirs may be a considerable distance apart and yet maintain a considerable depth of water. Thus on the Lower Seine weirs at 13 miles apart give an available depth of 10 ft. As the river slope increases towards the source, the length of the reaches naturally becomes smaller in the same proportion.

In selecting the position of a weir due regard must be paid to the shape of the valley and the general slope of the ground and the accessibility of the lock approach.

Generally the site of the lock is in one of the two channels passing by an island, and the weir is placed in the other, or if there is no island, a channel is excavated in the concave bank at a bend (fig. 67) and the lock sited therein, whereas the weir is constructed in the old river channel.

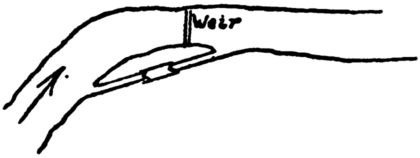


FIG. 67.

Where the variation of discharge is not great, as in the smaller rivers of Flanders, a lock and weir can be constructed, as in fig. 68, where a large centre pier of masonry separates the weir channel from the lock.

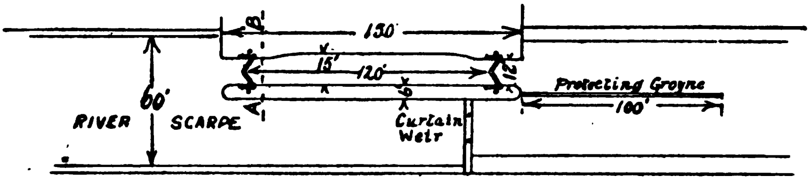


FIG. 68.

The weir is usually placed at the downstream end of the island or pier to lessen the risk of barges being caught in the current.

In the case of the lock illustrated, where the approach channel is very near to the weir and is likely to be effected by the current, it becomes necessary to build a protecting jetty out from the pier, and for at least 100 ft. downstream.

The weir is of the movable type, and can be completely opened to allow of the passage of flood waters.

The great gain of depth due to conversion of a river into a series of reaches is shown in fig. 69, where the flood level entirely submerges locks and weirs and the summer level is but one-sixth of the present summer level.

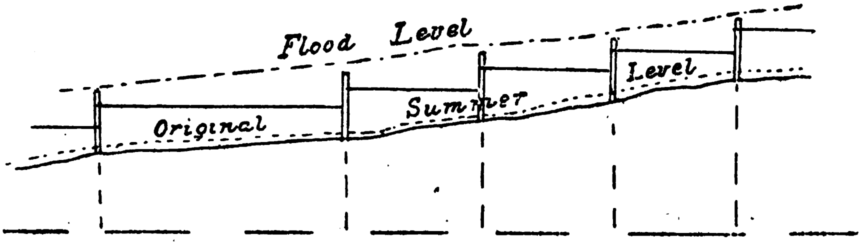


FIG. 69.

It may be necessary to add a low embankment to the river in places, as shown in fig. 70, which is a section of the river Scarpe. This latter river is a very good example of what can be accomplished by a judicious canal scheme.

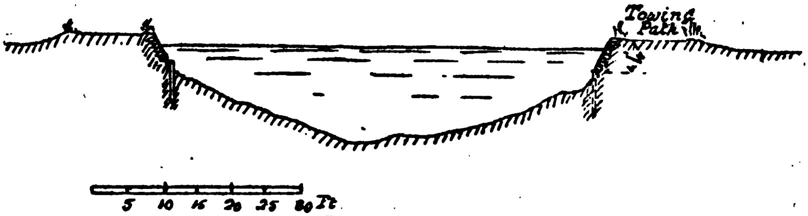
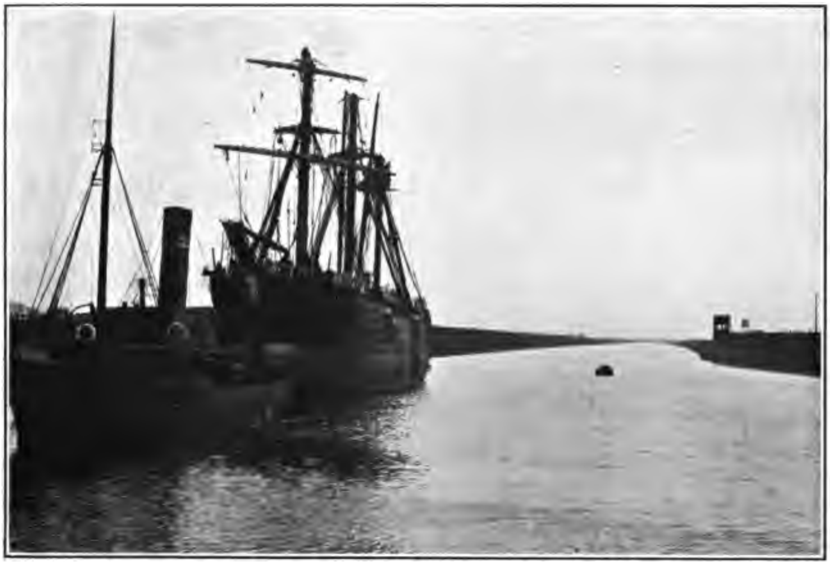


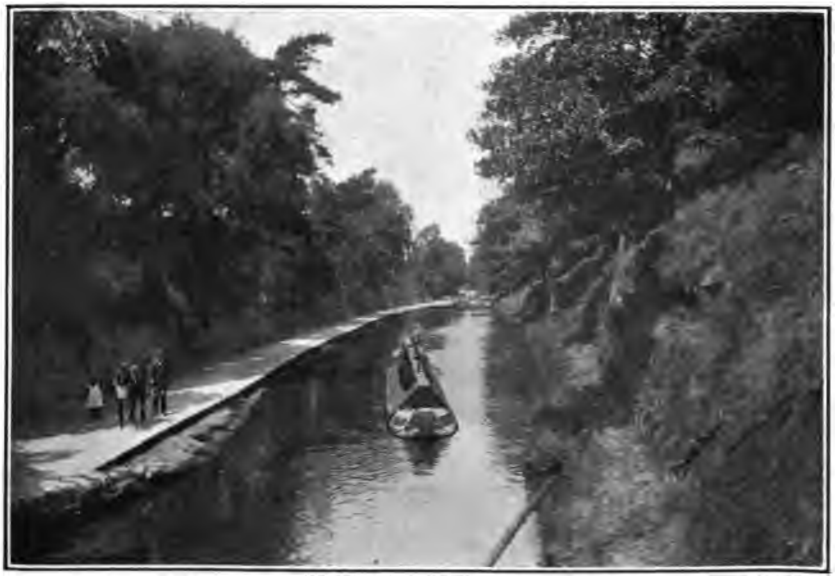
FIG. 70.

It was originally a very small river, and has now been converted into a moderate sized water-way of great importance to industrial France. It is modelled on a very economical plan, and requires very little expense for maintenance. The length of the reaches varies from 2 miles to 5 miles for an available depth of 8 ft.

PLATE XI.



A.—MANCHESTER SHIP CANAL.



B.—CANAL IN SANDSTONE CUTTING.

To face page 96.]

The cross-section of a masonry pier lock is shown in fig. 71. The lock is filled and emptied by means of sluices in the lock gates, which are built entirely of wood. The flushing of the lock approach on emptying the lock keeps the channel clear of silt, etc.

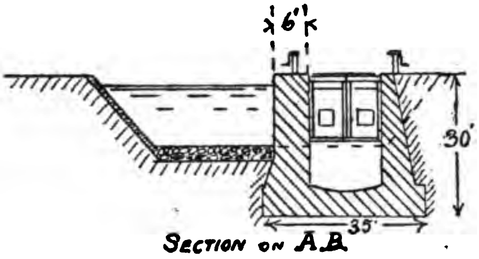


Fig. 71.

The upper terminus or dock at the head of the canal should have some stream of ample discharge diverted into it so as to replenish the waters lost in locking.

The head dock of the river Scarpe, situated in Arras, is built in the valley of a small tributary stream (fig. 72), and obtains its waters from this source. The capacity of this head dock should be as large as possible, so that the water level at the quays will not be seriously affected after locking a good deal of traffic.

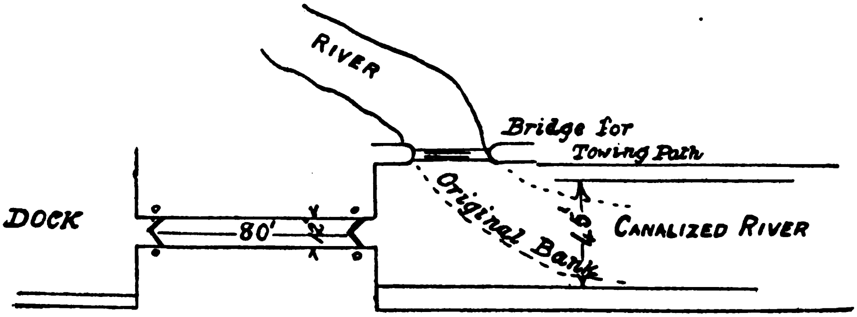


Fig. 72.

The flushing arrangement for the channel is provided by sluices in the lock gates. In large locks, to save time in filling and emptying, sluice channels are built in the side walls.

Weirs.—There are two distinct types of weirs, solid and movable, and both have their good points.

Solid weirs require very little maintenance, but as they obstruct the channel to the extent of the gain of depth the height of flood level is increased in proportion, and their use is limited at the present time to rivers with high banks and in country where the damage from floods is not important.

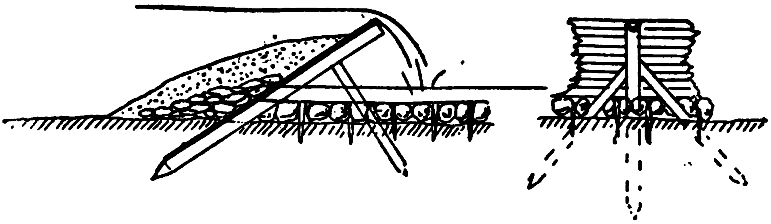


FIG. 73.

The most primitive type of solid weir is that of fig. 73. Though of extremely rough and light construction, they have stood for as long as 10 years without damage, holding 3 ft. head of water.

Where cost is to be kept at a minimum in undeveloped country the types shown in figs. 74 and 75 are particularly useful. The former is the best for sandy bottoms and the latter for hard rocky beds. They are both constructed of timber (rough-sawn), and put together in sections on shore and then floated or transported to their positions. Fig. 74 has a row of 2-in. sheet piling driven in at the nose and a 20-ft. apron extending downstream at the fall, to prevent erosion of the bed. The frames are 18 in. apart centre to centre, and the main members are 9-in. × 6-in. section, stayed by double 3-in. planking. The whole is boxed in 2½-in. sheeting and filled with stones.

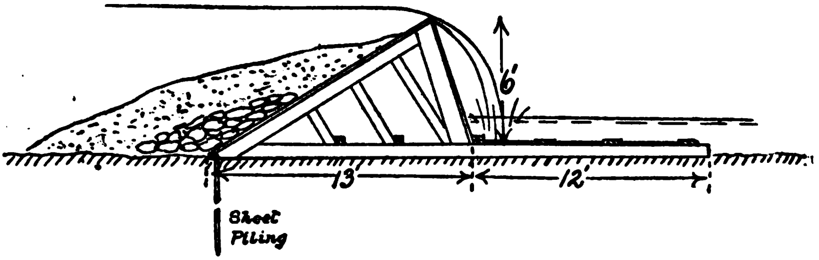


FIG. 74.

The second type is of 6-in. × 9-in. timber for the top member and vertical strut, while the rest of the frame is of 3-in. × 9-in. planking. The frames are 15 in. centre to centre, and are strengthened longitudinally by 6-in. × 6-in. sparring.

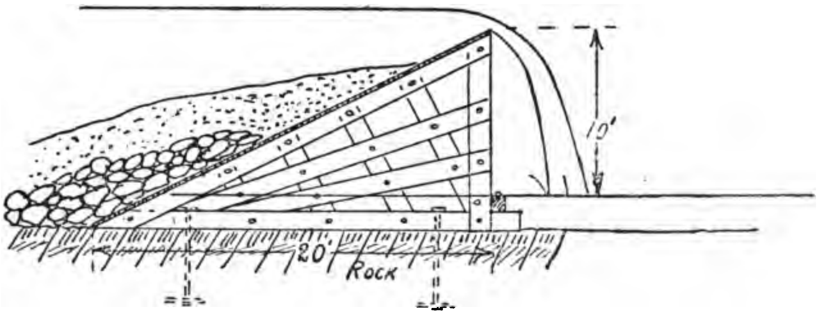


FIG. 75.

The main consideration in the success of these weirs is to ensure that the frames are well-bedded and are under no initial stress.

A more expensive but more adaptable type is that of fig. 76. The whole of the construction is carried out with

3-in. × 9-in. planking and 2-in. pile sheeting. The design of the apron and sluice panels is particularly effective, and the large amount of sheeting used effectively prevents any failure during times of flood. Triangular boxes are separated by 3-ft. sluice panels, which can be taken from their slots on the approach of the wet season, and if the passage is not entirely free it is not seriously impeded. This type of weir has stood several severe floods without the slightest damage, even though the length of the crest was over 2000 yards.

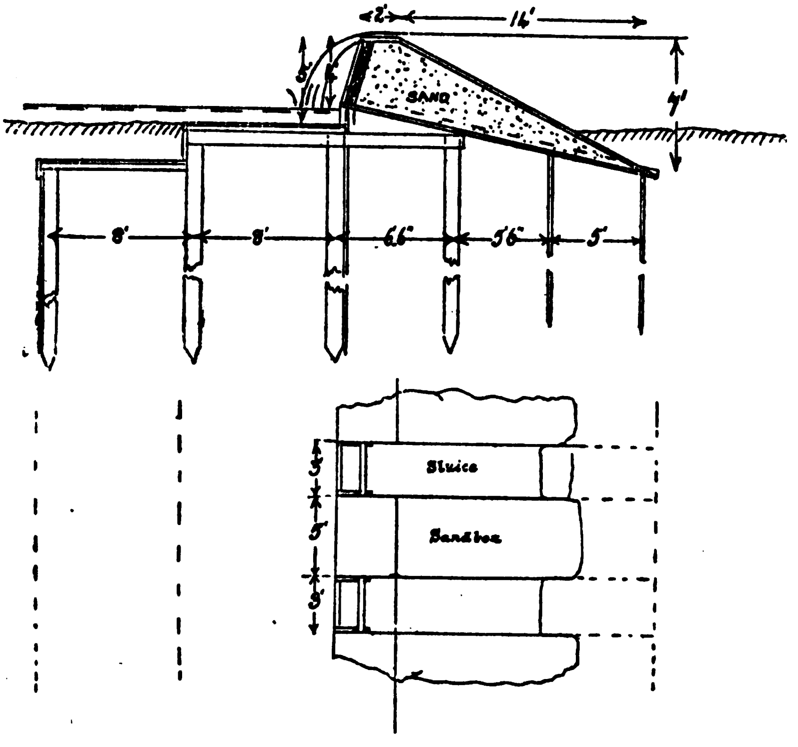


FIG. 76.

There are many types of solid weirs built of masonry or rubble-stone.

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The segmental or arched type often takes the general form of fig. 77, and is built of cut-stone masonry; being very expensive, it is not suited for large rivers.

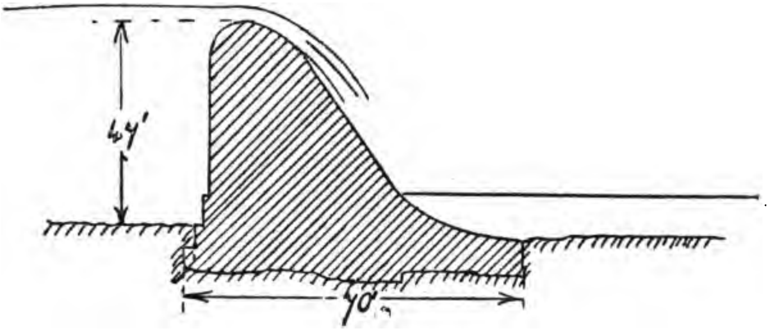


FIG. 77.

The concrete weir (fig. 78) has three curtain walls, and the toe wall is scooped out so that the shock of the overflow is absorbed before reaching the toe and scouring out the gravel bed.

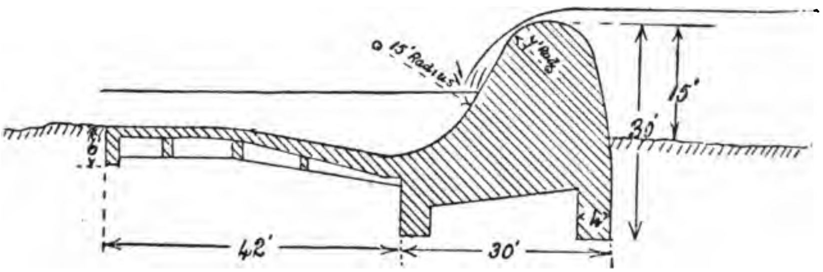


FIG. 78.

A very good type is that shown by fig. 79, with a stepped downstream face. It is suitable for any head of water, and is exceedingly durable. The front face can be made flat instead of in steps, but then a great deal of scour takes place at the toe, which is avoided by the steps.

The construction is of rubble with hand-packed facing blocks.

Oblique weirs were originally designed with the idea that the greater length would lessen the height of water on the crest. In practice this result has not been attained, and the idea has been abandoned for the more practical method of selecting a broad part of the river.

The shape of the upstream face and crest of a weir affects the discharge. If the upstream face is inclined into the current, the discharge is only 0·95 that of a weir with a vertical face; on the other hand, if the inclination is downstream or with the current the discharge is increased to 1·1 times that of a vertical face.

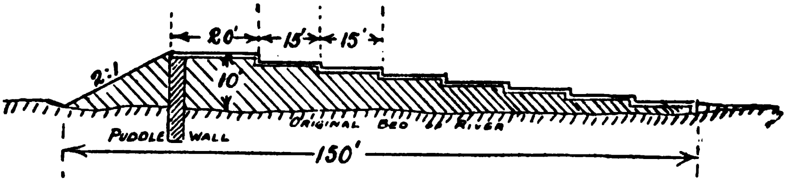


FIG. 79.

The discharge is also increased by rounding off the inner edge of the crest.

A broad flat-topped weir has considerably less discharge than one with a rounded crest.

Movable Weirs.—The commonest type of movable weir is that known as the "Needle" weir (fig. 80). The name is derived from the long square spars forming the face of the weir, abutting on the stone sill on the river-bed and resting on the top edge of the trapezoidal framework. The needles are of wood, and varying from 3 to 4 in. square projecting above the deck of the framework, so that the weirkeeper can manipulate them when required. They can either be entirely removed or eased forward at the top alternately to regulate the discharge.

On the approach of floods the needles are removed and the frames lowered on to the bed of the river.

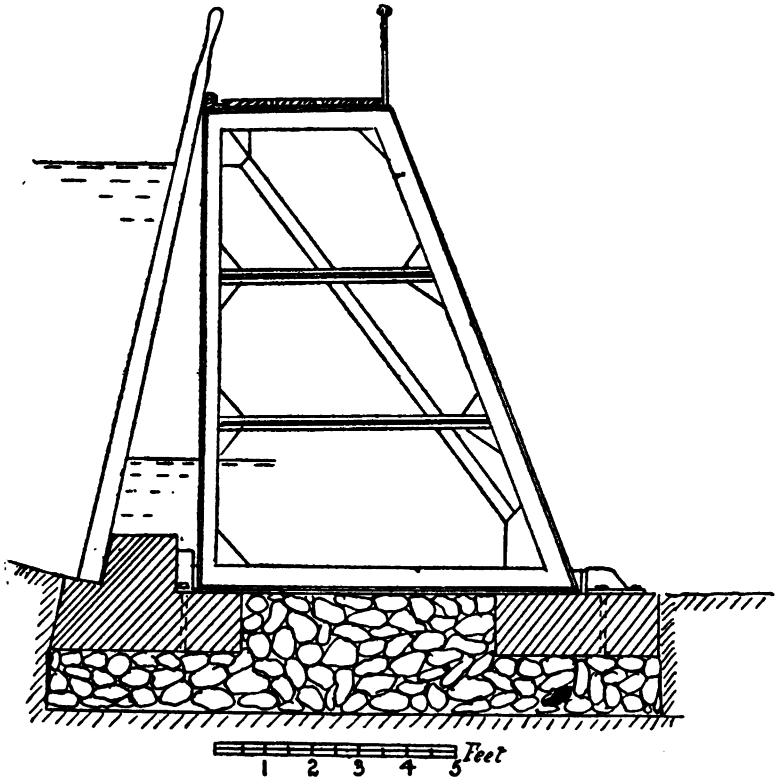


FIG. 80.

In curtain weirs or panel weirs, the place of the needles is taken by curtains and panels respectively, manipulated from the deck of the frames.

There are several other types of movable weirs working on the same principle.

The *Bear Trap* weir consists of two shutters (fig. 81), which to allow passage of flood waters lie flat on the bottom. To raise the weir water is admitted to the underside of the leaves. It is only suitable for very small dams.

The movable weir has the advantage over the solid weir, in that it is only a temporary impediment to the flow of river and can be removed at pleasure.

Great care must be exercised in the protection of the banks up and downstream of the weir abutments.

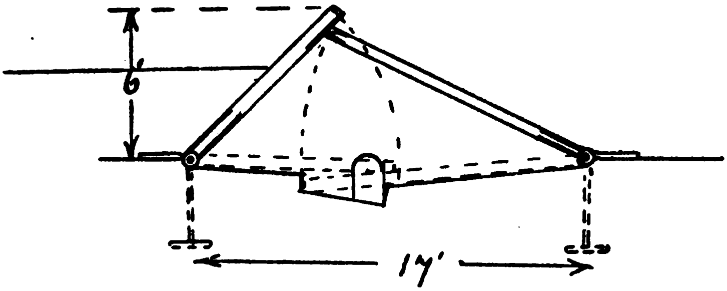
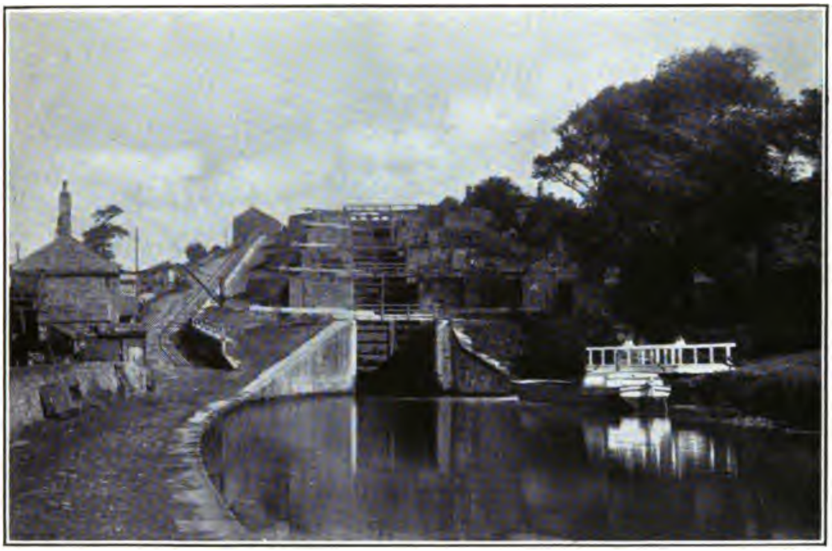


FIG. 81.

"A" Weirs.—A type of weir becoming very popular is that indicated in fig. 81*a*. A series of strongly-made steel trestles of inverted V-shape are hinged on to the foundations. The units fit closely together on the upstream face, and are about 24 in. wide. At the toe of the upstream face three baulks of timber are securely bolted to the foundations, the upper timber being fitted and shaped to act as a sealing joint into which straw can be dropped if necessary. No attempt is made, however, to make it watertight, as leakage at the foot helps to avoid the accumulation of detritus. On the approach of floods, each unit is lowered independently on to the bed, where

PLATE XII.



A HEAVY FLIGHT OF FIVE LOCKS—BINGLEY.

To face page 104.

they all lie snugly, offering very slight resistance to the

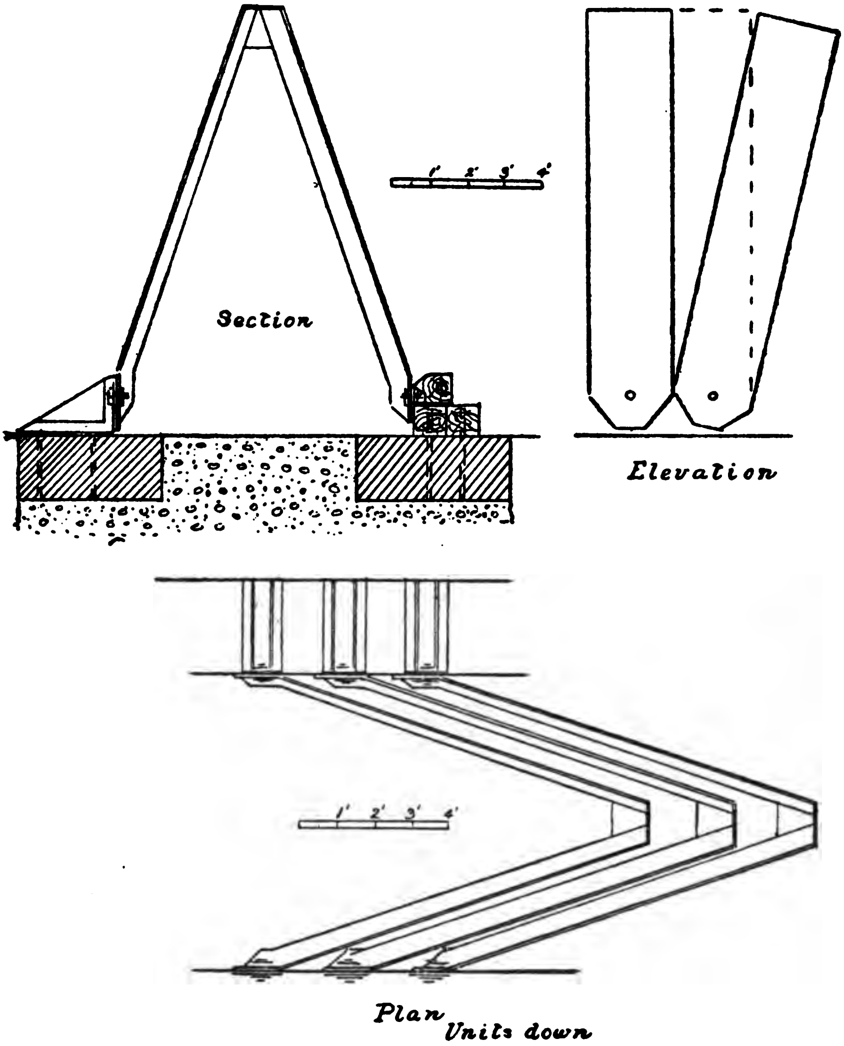


FIG. 81a.—"A" WEIR.

passage of the flood waters. The upkeep of this type is a minimum, and all labour of lowering units can be done by two men, no matter what head of water is against the face.

As all units are similar, and the foundations are narrow, it will be seen that the first cost must compare very favourably with all other types of movable weirs.

Dams.—The distinction between dams and weirs is

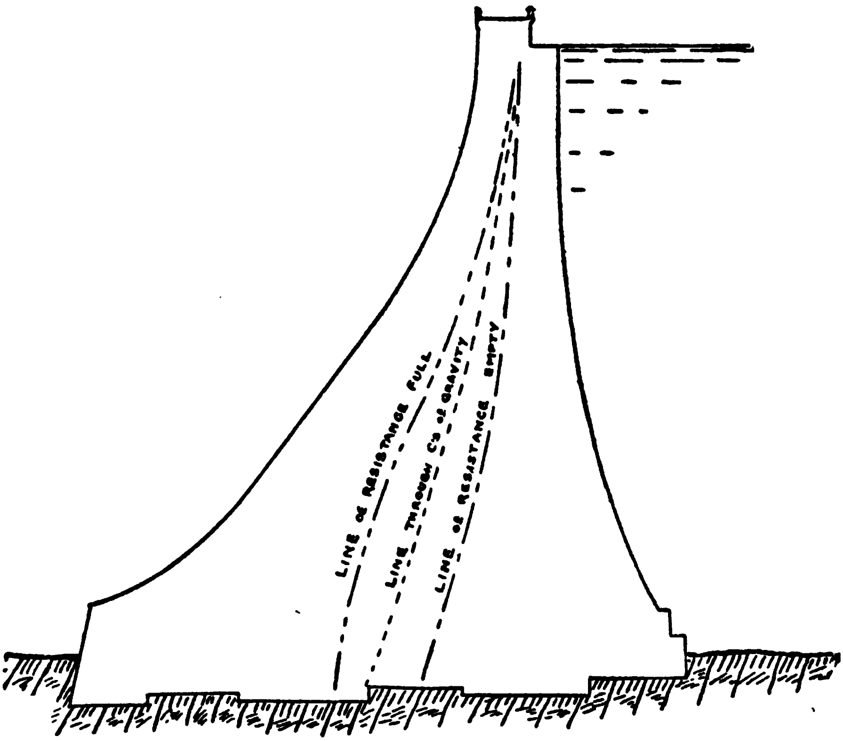


FIG. 82.

that the function of the former is to store up water, whereas the latter is to increase the level of the water without regard to the capacity.

The general construction of low dams is that of solid weirs, but when the height of the dam exceeds 50 ft. it becomes necessary to adopt a more economical shape, as, for example, the Furens dam (fig. 82).

This shape is arrived at in the following manner: Let P_1 be the pressure of water acting on the block 1, at one-third the depth cutting the vertical through the centre of gravity G, as shown in fig. 83. Then by the parallelogram of forces we have the resultant of weight and water pressure acting through the point R on the joint between blocks 1 and 2.

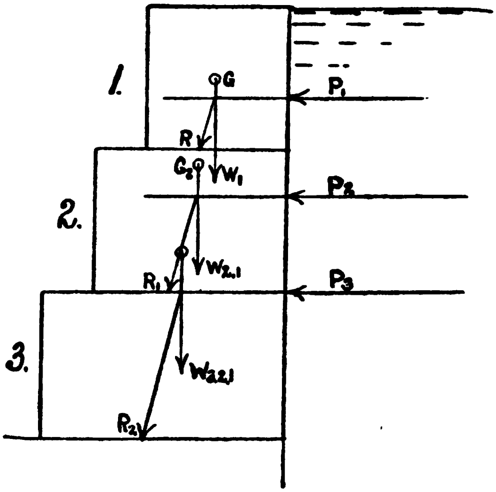


FIG. 83.

For block 2 the water pressure P_2 is that due to the depth of the two blocks below the water surface, and the centre of gravity is also that of the two blocks. Therefore the resultant cuts the joint at R_1. The same procedure is carried out for the whole series of blocks forming the dam, and the line drawn through RR_1R_2 is called the line of resistance of dam when full, or line of pressure, and this line must be entirely within the middle third.

The dam must be splayed out to bring about this result.

In like manner, where the verticals through the centres of gravity cut the joints draw a curve, which will represent the line of pressure of dam when empty (fig. 82); this must also fall within the middle third, if not the face must be splayed out until it does so.

Masonry dams constructed in this manner have been highly successful. In the construction the usual precautions of security against sliding and water-tightness of the joints have to be observed, and provision made by sluices to drain the dam or regulate the capacity; and to scour out the accumulation of detritus on the upstream face.

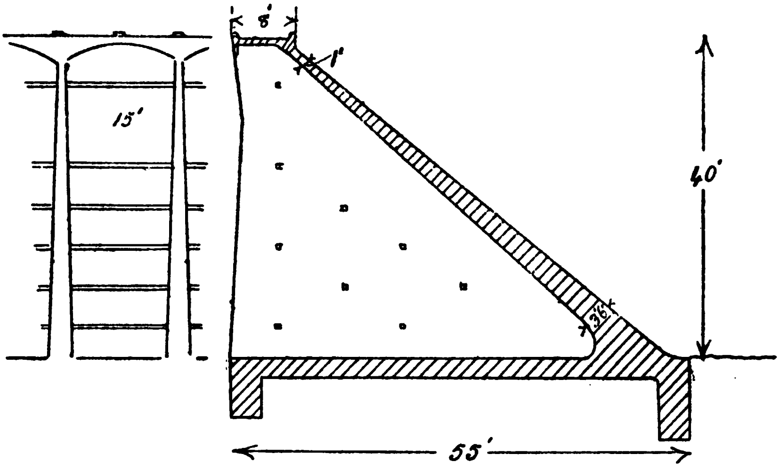


Fig. 84.

Latterly, reinforced concrete is becoming more popular for the construction of dams. The type usually adopted is that of fig. 84, where a sloping upstream wall is supported by vertical buttresses connected laterally by reinforced concrete beams. Vents are left in the apron to prevent failure from upward pressure. The mixture most satisfactory is 1, 2, 4 of cement, sand, and aggregate respectively.

A much greater factor of safety than in ordinary buildings or structures is necessary. The few failures registered with this type of construction have been due to defect in design of curtain walls.

CHAPTER X.

CANALS.

Location.—The location of canals is unlike that of railways, insomuch that it is advisable to keep to a level stretch as long as possible, and then make a rapid descent by a flight of locks, or lift. By this means the time of passage is reduced, and half the number of lock-gates is required.

When traversing a valley it is advisable to run the canal on the firmer and less porous soil of the side slopes. The passage of a stream across a canal is effected by means of a culvert in embankments and an inverted siphon in cuttings. A canal located in a river valley must have its banks raised above maximum flood level.

Embankments.—Where the canal passes over low-lying ground great care must be exercised in the design and construction of the embankments. All earth-fill must be well rammed, and should be carried up in layers of not more than 8 in. thick.

The usual method of preventing leakage or seepage through the embankment is by the construction of a puddle wall or layer round the wetted perimeter, consisting of one part sand and one part clay, well rammed and compressed to 60 per cent. of its original volume. The puddle wall should extend from 6 in. above maximum water level to 3 ft. below the natural surface of the ground.

Where the puddle is placed in the form of an inner lining (fig. 85) it is usually protected from abrasion of the barges by a further lining of 2 to 3 ft. of ordinary soil or 1 ft. of a semi-puddle—2 parts sand, 1 part clay—compressed by grooved rollers on the bottom and rammed on the sides. Three excellent methods of puddling are illustrated by figs. 85, 86 and 87.

The best method of securing a watertight section is to place the puddle wall near to the inner face, as otherwise the earth of the inner half of the embankment may become saturated and endanger the stability. To prevent serious leakage all loose material of the original surface should be removed before proceeding with the earth-fill.

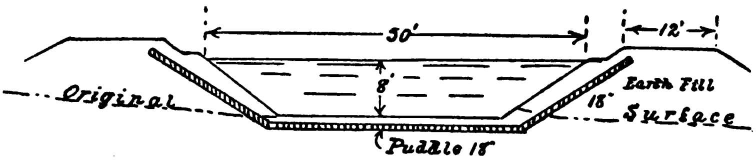


FIG. 85.

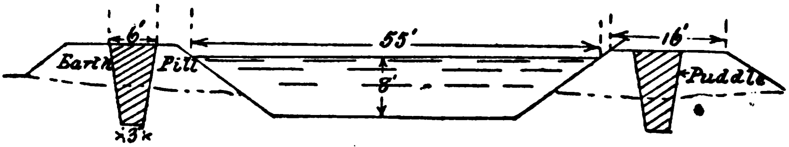


FIG. 86.

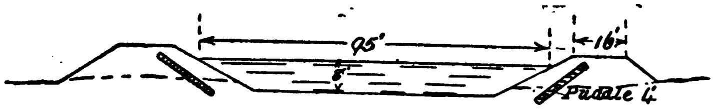


FIG. 87.

Where the bottom lining of a canal, when run dry for repairs, is subject to an upward water pressure, tending to break the puddle flat, under-drains with free outlet become necessary.

A canal running in long embankments and liable to cause damage by failure to surrounding country, is divided up into a series of lengths by stop gates. These are simply drop gates or planks working vertically in grooves in narrow canals, and similar to lock gates in canals of larger section.

Their function is to shut off the damaged section without laying bare the whole reach.

Cross-Section.—The area of the cross-section of a canal depends upon the class of traffic which it is proposed to carry. The bottom width is generally taken, for slow-moving traffic of 2 miles per hour, as $2\frac{1}{2}$ times the beam of a barge, and with higher speeds is increased in proportion. The width at bends is greater than on the straight to allow for turning. There are several rules for finding this increased width, but the best and simplest is the following:—

$$W = \frac{\omega + 2000}{R}$$

where $W =$ width at the apex of the curve in feet (when curve exceeds 6° curvature).

$\omega =$ width on straight reaches in feet.

$R =$ radius of curve in yards.

The slope of the sides varies with the quality of the ground. Typical cross-sections are those of figs. 85, 86, 87. The depth is dependent on the speed and draught of the loaded barges.

The minimum clearance between the keel of a barge or vessel and the bed of the canal is—

(*a*) For inland canals of average depth of 8 ft., 15 in.

(*b*) For large ship canals of 25 ft. and above, 4 ft.

The protection of canal banks is carried out in a similar manner to that of canalized rivers. The most destructive agent of the banks is the wash of small fast boats, but ample protection is afforded by stone pitching to a depth of 4 to 5 ft. below water level, even on very deep canals, such as the Manchester Ship Canal, where small launches sometimes attain the speed of 15 miles per hour.

The shape of the cross-section or canal prism is naturally dependent upon the quality of the ground passed through. In ordinary soil the side slopes are usually 2 : 1, any steeper slope requiring protection by paving or mattress. In passing through valuable ground built vertical side walls are advisable.

In England the bottom width of most of the inland canals is only 25 ft., having at a depth of water of 5 ft. a surface width of 45 to 50 ft., whereas in France the bottom width is 33 ft. and surface width 56 ft. with a minimum depth of 6½ ft.

Water Supply.—The water supply of a canal is obtained by tapping adjacent streams or rivers, or by pumping, as in France. When water is obtained by former method great expense will be avoided if it is allowed to pass through a settling basin, where all silt will be deposited before entering the canal.

The cost of pumping, including upkeep of plant, on French canals works out at one penny per 10,000 cubic ft. raised 1 ft.

The loss from evaporation and leakage varies from 20 to 100 cubic ft. per mile per minute for canals of average width of 50 ft., and to make up this loss it will be necessary to ensure that a constant supply be available in the dry season.

The loss at locks is sometimes made up by pumping the water back from the lower to the upper level.

The distribution of water supply from reservoirs should be distributed throughout the length of the canal, and should on no account be confined to summit level.

The water supply derived from streams being a variable quantity provision has to be made by waste weirs or sluices to dispose of all surplus water in rainy weather by discharging it over the canal bank into adjacent streams.

The Irlam sluices on the Manchester Canal are designed for a discharge of 26,000 cubic ft. per sec.

The waste weir should have its crest not less than 6 in. and not more than 9 in. above the normal level of canal—the length of the crest depending upon the quantity of water to be discharged during flood.

It is current practice on French canals to lay dry the reaches annually for repairs. This is effected by waste-gates placed at bottom level and discharging into neighbouring water-courses.

The leakage at these gates in the smaller canals varies from 1·5 to 2 cubic ft. per mile per min., depending upon the depth of water.

On refilling double the volume is required, for almost a volume equal to the capacity of the reach is absorbed by the earth before regaining its normal condition.

The loss of water by percolation varies greatly. In new or repaired sections it may attain 800 cubic ft. per min. per mile, but generally is equal to 100 to 150 cubic ft. per min. per mile. In cuttings where seepage may take place an 18-in. puddle wall will effect a cure. Generally water-tightness increases with use due to silting up of the earth pores, and redeepening is attended with a temporary loss of water, until the bed recovers its usual condition.

Locks.—The old-fashioned practice of selecting an easy and uniform grade for the line of a canal is gradually being abandoned in favour of the selection of long level stretches between locks.

The former method requires a large number of locks of short lift, and generally follows a more winding course, whereas the present-day introductions of high lifts not only shortens the length of the canal but reduces the number of locks necessary, and hence effects a considerable saving in maintenance, labour, and time of passage.

The stretch of the Kennett and Avon Canal at Devizes (plate B, *frontispiece*) illustrates in a forceful manner the enormous waste of time required to negotiate the large number of locks on this gentle slope. Compare this photograph with the flight of locks on the Leeds and Liverpool Canal at Bingley (plate XII). There are only five locks against eleven on the former for the same rise, so that traffic can be carried on at almost twice the speed.

The construction of high lifts, however, can only be carried out when good foundations are available; this is particularly necessary with hydraulic or pneumatic lifts.

The hydraulic lift is constructed on the counterbalancing principle (fig. 88). There are two tanks or boat-chambers, supported on large rams working in cylinders sunk in the bottom of the lower level canal. The cylinders are interconnected, and the rams or pistons have contrary movements, that is, one rising as the other descends.

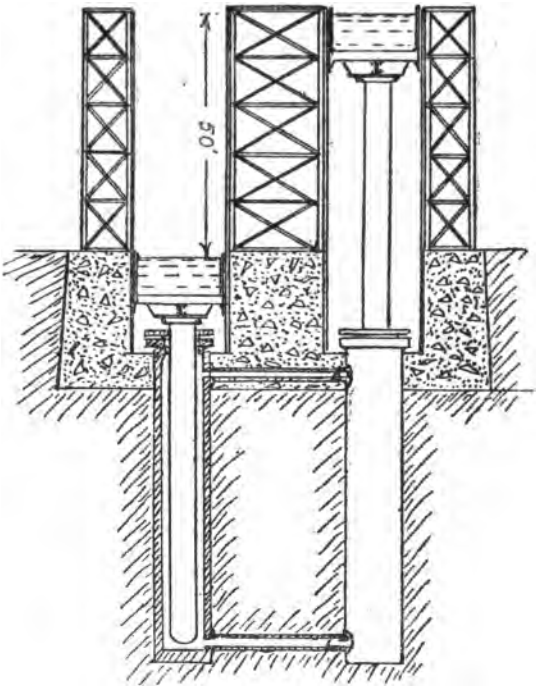


FIG. 88.

The system is put into operation by admitting an excess of water into the upper tank, causing an increase of pressure on the ram which, being transmitted by the liquid to the other cylinder, causes the lower ram to rise. The boat-chambers work in vertical guides.

The hydraulic lift, however, has not been very successful, for after a time the rams get badly scored and traffic has to be held up while repairs are effected. This has been overcome in some cases by counterbalancing each chamber independently and operating them by electric machinery.

On canals using this type of lift, the height of the lift is 50 to 65 ft., and with tanks of a capacity of 1500 to 2000 tons the time of rise is 1½ to 2 minutes.

The pneumatic system, which also works with a pair of boat-chambers fitted with inverted air reservoirs, is operated on the same principle, the difference being that the ram is done away with and compressed air takes its place.

The lift of ordinary locks varies from 4 to 10 ft., and the dimensions of the locks are dependent upon the size of barge and the character of the traffic. On the English barge canals they vary from 60 ft. long, 12 ft. wide, and 5 ft. water on the sill to 300 ft. long, 22 ft. wide, and 10 ft. water on the sill in the pioneer and busy midland canals respectively.

In France the dimensions (minimum) of all locks are fixed by law at 126 ft. long, 17 ft. wide, and 6½ ft. depth of water on sill.

The tendency in all reconstruction of canals is to decrease the number of locks and increase the lift and length of level reaches.

Leakage at locks on small canals of 17 ft. width and 6½ ft. depth is estimated at 15,000 cubic ft. per diem to 500,000 cubic ft. in locks 40 ft. by 12 ft., and becomes as great as 72 cubic ft. per sec. on the Weitzel Lock of the St. Mary's Falls Canal, U.S.A., which is 60 ft. wide by 20 ft. sill depth.

It is advisable to construct the locks of generous dimensions for two reasons of equal importance—

(*a*) An increase of prosperity will occasion an increase of capacity of barges, and a greater depth and length will have to be accommodated in the lock.

(*b*) The time of locking is affected by the resistance of the water to the entrance of a loaded barge, unless there is sufficient clearance between the hull and the lock sides to enable the water to escape from the lock.

Lock-Gates.—The pioneer type of canal, such as our older English canals, work well with the lever pattern gate, which for the traffic using them is perfectly adequate, but with more heavily laden canals used by vessels of 600 to 1000 tons burden more up-to-date appliances are required.

Wooden gates are less expensive and much more durable than steel, on the smaller canals.

The larger type of locks of 40 ft. width and over are generally fitted with steel arch gates bearing on a V-shaped sill (fig. 89). They have timber quoin or heel and mitre posts which, bearing up against the side of the lock and mitring in the centre, form a more water-tight joint than steel to steel.

Where the gates are over 30 ft. width it is usual to operate them by machinery, and where possible the power is derived from the head of water in the upper reach.

The smaller locks are generally filled and emptied by sluice valves in the gate itself. In large locks, however, this is impracticable, and a large sluice-way in communication with upper and lower levels with two-way valves at each end is built in the side walls of the lock.

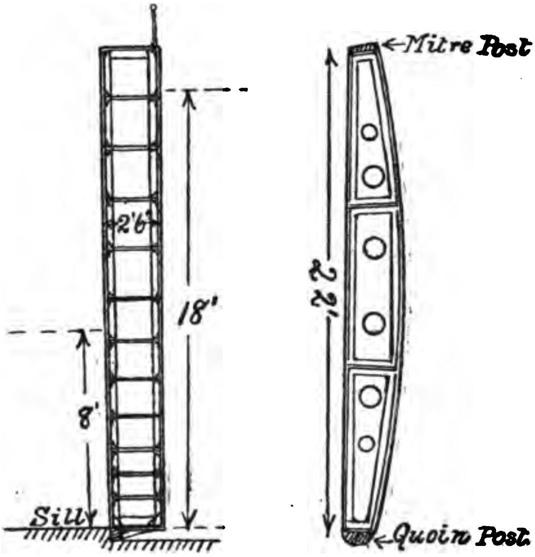


FIG. 89.

The sluice channel has several ports or openings branching into the side of the lock, and through these the water is distributed evenly throughout the length, thus preventing the surging of the vessel being locked.

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